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ON A POSSIBLE FUNCTION OF DISRUPTIVE APPROACH IN THE FORMATION OF METEORITES, COMETS, AND NEBULÆ.[1] [2]

ACCORDING to a familiar doctrine founded on the researches of Roche, Maxwell, and others, a small body passing within a certain distance (the Roche limit) of a larger dense body will be torn into fragments by differential attraction. In reality, the doctrine is applicable to the close approach of any two bodies of sufficient mass and density, but, as this more familiar case of a small body in close approach to a larger body is the one supposed to be involved in the origin of comets and certain meteorites, it will at first be taken as representative, and the wider application of the doctrine will be considered later.

The sphere defined by Roche's limit is computed on the basis of a liquid body whose cohesion is negligible, and whose self-gravitation alone is considered. It is obvious, therefore, that when cohesion is a notable factor, a small body might pass through the outermost part of this Roche sphere without suffering disruption, but that, if a nearer approach were made to the large body, fragmentation might take place. There is, therefore, a sphere within the Roche limit—which may be called the

[1] I am greatly indebted to Dr. F. R. Moulton for suggestions and criticisms, and for formulæ for certain auxiliary computations that do not appear in the paper. I am under obligations to Mr. C. E. Siebenthal for the diagrams and other aid.

[2] From THE ASTROPHYSICAL JOURNAL, Vol. XIV, No. 1, July 1901.

sphere of disruption—which is applicable to solid bodies as distinguished from liquid bodies.

The size of this sphere of disruption compared with the Roche sphere depends, among other things, on the coefficient of cohesion and the size of the body to be disrupted. The coefficient of cohesion being the same, the sphere of disruption is relatively smallest when small bodies are to be disrupted, and becomes larger as the size of the body increases until it is sensibly as large as the Roche sphere. To illustrate this concretely, let disruption be supposed to take place along a diametrical section normal to the gravitative pull, dividing the body into halves. Let the bodies to be disrupted be spherical and homogeneous. The cohesion to be overcome will then obviously vary as the areas of the diametrical sections, and these areas vary as the squares of the radii of the bodies. But the masses of homogeneous spheres vary as the cubes of their radii, and the gravitative pull varies as the masses, modified by the differential tidal pull. It follows that mutual gravitation will more effectively disrupt large bodies than small ones. The limit at which the fragmentation of a solid body will take place will therefore approach more and more closely that of a fluid body as the size of the solid body becomes larger. For solid bodies of considerable dimensions, as asteroids, for example, the limit of disruption approaches sufficiently near Roche's limit to make the difference negligible in a general discussion. This will appear the more evident from the following numerical considerations.

Experimental data as to the tensile strength of rock are very limited, as the material is rarely used where tensile stresses are involved, but all the results of experimental tests given in Johnson's *Material of Construction* fall notably below 1000 pounds to the square inch, and this figure may be assumed as a liberal representative estimate. The weight of representative rock may be taken as $\frac{1}{10}$ pound per cubic inch. The tensile strength of an inch cube is therefore to its weight, at the surface of the earth, as 10,000 to 1. Using the same data, the tensile strength of a mile-cube of rock is to its weight as 1 to 6.36,

while that of a 100-mile-cube is as 1 to 636. It will be seen, therefore, that in a comparatively small body the cohesive resistance to disruption bears a very small relation to the gravity of the mass, and that for large bodies it is negligible. For such bodies, the Roche limit may be taken as appreciably the limit of the sphere of disruption.

These numerical considerations, however, show that fragmentation by differential gravity acting alone will not become minute in any such case as that of a satellite or asteroid making a near approach to one of the planets.

But there are additional considerations that influence the practical result. The outer portion of the earth, and doubtless that of the satellites, asteroids, and cold planets generally, is deeply traversed by fissures—oblique and horizontal as well as vertical—which render it little more than a pavement of dissevered blocks which could be lifted away with little resistance beyond that of gravity. The relief of pressure upon the less fissured portion below, which would follow upon the removal of the overlying fissured portion, and the sudden exposure of this under portion to a lower temperature resultant from this removal, would develop new stresses; and these would doubtless give rise to additional fissuring and further easy removal, and thus the process would be extended. It is not improbable that the sudden rending open of a sphere that is hot within and the consequent exposure of the highly heated rocks in the interior to much lower temperatures would result in sufficiently great differential contraction to minutely disrupt the fragments irrespective of differential gravitation. The central portions of a body sufficiently hot to melt at surface pressures would doubtless pass immediately into the liquid condition on the removal of the pressure of the overlying rock, and this passage might, not unlikely, take on eruptive violence by reason of the included and highly compressed gases—or substances in a potentially gaseous state—in which case an extremely minute division would ensue. In the case of the earth, there is good reason to believe that if its interior gravitative stresses were suddenly

removed, its internal elasticity would disrupt its exterior with much violence; and if the gravitative stresses were more gradually removed, the disruption would still be complete and pervasive, though less violent. How far a similar view may be entertained with reference to small bodies like the asteroids is uncertain, but even in these it is not improbable that the internal elastic factors would offset in some large part, if not entirely, the restraining force of the general cohesion of the mass.

From these considerations it would seem that the sphere of disruption, even in solid bodies of the nature of satellites and asteroids, may closely approximate to the theoretical Roche limit, while, for large bodies intensely compressed and very hot within, the practical sphere of disruption might actually exceed the Roche sphere. In the case of large gaseous bodies like the sun, intensely heated and compressed in the central portions, the disruptive or dispersive sphere must be much larger than the Roche sphere. But of this later. For the smaller solid bodies, and for present purposes, it may be assumed that the sphere of disruption is practically defined by Roche's limit.

The size of the sphere of disruption compared with the size of the body producing the disruption is an essential point in this discussion. The relative magnitude of these varies for every couplet of bodies brought under consideration, because it is dependent on density, cohesion, internal elasticity, and other varying factors. Roche has shown that, if the two bodies are incompressible fluids of the same density, and without cohesion, the limit of disruption is 2.44 times the radius of the body producing the disruption. The cross section of this body will therefore be to the cross section of the Roche sphere as 1 is to 5.95. The disk of the outer ring of *Saturn*, compared with that of the planet, whose density is unusually low, is a trifle below this ratio (1:5.29), but may be taken as a practical sanction of the figure theoretically deduced. The disk of the Earth, a dense body, is to the disk of the Roche limit, as computed by Darwin, as 1 to 7.5. It may therefore be concluded that where planets

and planet-like bodies are concerned, the sphere of disruption has a cross section from 5 to 7.5 times as great as the central body It follows from this, that to a passing body the sphere of disruption exposes a disk five to seven times as great as the central body, and hence there are from four to six times as many chances that the passing body will invade the sphere of disruption without collision, as that it will strike the central body. In other words, *the fragmentation of a small body by near approach to a large one of the nature of the planets will be from four to six times as imminent as actual collision.*

That disruptions or explosions of some kind actually take place in the heavens, and that not uncommonly, seems to be implied by the sudden appearance of new stars, often with great brilliancy, followed by rapid decline to obscurity or extinction.[1] Five such new stars have been recorded during the last decade, and the survey of the heavens during this period has not been entirely exhaustive. The appearance of such new stars has been referred to collision, but their frequency has been felt to be an objection to this view, and other explanations, of the nature of eruptions or explosions, have been offered, but usually without assigning any probable cause for such extraordinary explosive action. The numerical objection is, in some measure, removed if the possibilities of disruptive approach be added to those of collision; and it will be seen further on that special conditions giving rise to distant approaches that are merely disturbing at the outset, may ultimately give rise to large possibilities for disruptive approaches.

That bodies pass within the disruptive sphere of other bodies is known from the fact that at least four comets have been observed to pass within the Roche limit of the sun, and these would quite certainly have been torn into fragments if they had not already been in that condition. There are, therefore, some observational grounds for the view that instances of bodies passing through the disruptive spheres of other bodies are not so rare as to render their results unimportant.

[1] A fact which has become very familiar and impressive, since this was written, by the appearance of *Nova Persei.*

In the considerations now set forth, there seems to be warrant for the proposition *that solid bodies may suffer fragmentation without actual collision with other bodies, and that the bodies so disrupted may constitute comets so long as the fragments remain clustered, and that when these fragments become dispersed, they may constitute one variety of meteorites.* Only the first part of the proposition is novel—if indeed that is—for the disintegration of comets into meteorites is an accepted doctrine. The characteristics of comets other than their fragmental structure will need to be considered, but this may best be taken up later.

The foregoing conclusion, as a purely ideal proposition, does not appear to need discussion, unless the fundamental deductions of Roche, Maxwell, and others are questioned. Nor does its application to the adventitious cases of wandering bodies permit definite discussion, for neither the nature nor the number of such bodies is known; nor is the likelihood of their close approach to other bodies capable of estimation. But, on the probable supposition that the stars are centers of systems like our sun, there are hypothetical cases of approach of these systems to each other that by disturbance of the planetary orbits may lead on to disruptive approach of the individual bodies, and thus give effective application to the doctrine; and these invite consideration. It must be confessed that these cases, likewise, cannot be discussed with much satisfaction, since the movements of the assumed solar systems and their relations to each other are but very imperfectly known. Present data, however, warrant the assumption that the stars and their attendants are moving in various directions at various velocities, and that they are probably not controlled by any central body; nor do they probably follow concentric orbits so adjusted to each other as to forbid close approaches. The conception that the movements of the stars are somewhat analogous to those of the molecules of an exceedingly attenuated gas in an open space, actuated by the attraction of their common but dispersed mass, seems the most probable that can be entertained in the present state of knowledge. It may at least be made the basis for the assumptions necessary to further discuss the doctrine in hand.

Let two stars be assumed to be attended by secondaries like those of the sun, and to pass each other near enough to initiate serious disturbances in the orbits of the planets and satellites of the two systems. It is not necessary that this disturbance shall be so great as to bring about a disruptive approach of any of these bodies at once, but merely that this shall be the ulterior effect, which may be long delayed. The two systems need not necessarily invade each other's actual limit, that is, the two suns need not approach each other within the sum of the radii of the orbits of their outermost planets.[1] For example, in the ideal case of two solar systems, it is not necessary that the orbits of the two *Neptunes* shall actually cut each other. If the undisturbed orbits merely touch each other, or even closely approach each other, it seems clear that if *Neptune* be at the time coming toward the point of such ideal contact, or near approach, the attraction of the passing sun, together with *Neptune's* own momentum, will carry the planet far beyond the limit of its own ideal orbit into the sphere of dominant influence of the passing sun. At the same time, the paths of the inner orbits of both systems will be distorted in a quite irregular way, dependent on their various positions in their several orbits. The transfer of an outermost planet from one system to another under these conditions of general disturbance, or any other radical change in the orbits of the outer planets, will quite certainly lead on to other disturbances of orbit, some of which may sooner or later lead to disruptive approach, though the result of such a complication is beyond the reach of precise prediction.

A still more remote approach between two systems in which the only result is a pronounced elongation of the orbits of the two systems, may ultimately result in close approaches, for, if the orbit of any of the planets of the two systems be elongated so that its perihelion distance is less than the aphelion distance of the next inner planet, or its aphelion distance greater than the perihelion distance of the next outer planet, a disruptive

[1] In the illustrative examples it is assumed for convenience that the planes of the systems are normal to the systems' lines of movement.

approach, although it will not necessarily follow, because the planes may not coincide, and for other reasons, may result — if not at once, at least ultimately — as a consequence of the shiftings and modifications which such a disturbed condition involves. For example, it is obvious that by a favorable conjunction with a passing system whose sun is distant from *Neptune* considerably more than the radius of his orbit, there may be an elongation of the orbit of *Neptune* so as to make it cut one or more of the inner orbits, and that further modifications may arise out of these relations which will either increase or decrease the eccentricity. The principles applicable here are identical with those that have been found to produce radical modifications of the orbits of comets and that have been worked out by H. A. Newton and others.

To embrace the full possibilities of the case, it is therefore necessary to consider (1) the effects of systems passing each other at distances varying from those in which the outermost planets do not even cut each other's orbits, down to center-on-center collisions, and (2) to take account of the ulterior effects of disturbed orbits, as well as the immediate effects. This last is a consideration of no small importance in the qualitative as well as the quantitative application of the doctrine, for it distributes the effects over an indefinite period of time, and does not require their coincidence with the passage of the systems. The ulterior effects, so far as the disruption of secondaries is concerned, may apparently be much greater than the immediate effects. If this is not already clear, let a specific case be taken, as, for example, two solar systems passing each other so that their centers shall be 500 000,000 miles apart at nearest approach. If the planes of the systems are transverse to their paths, the ideal undisturbed orbits of the asteroids will touch, or closely approach, or slightly cut each other, as the individual case may be. The ideal orbits of the *Jupiters* will fall but little short of the passing sun, while the ideal orbits of *Saturn*, *Uranus*, and *Neptune* will fall outside the passing sun. While the precise results of such an event cannot be computed, it is quite certain

that the secondary systems of the two suns will be most profoundly disturbed and the symmetrical and harmonious relations of the planetary orbits be utterly broken up. While even in this case the *immediate* contingency of a disruptive approach of one secondary to another may not be high, there will arise a *perpetuated series of contingencies*, the consequences of which will apparently be immeasurably greater than those immediately incident to the disturbing action, and the end of this perpetuated series of contingencies can scarcely be foreseen. Assuming that the great planets will exercise the same kind of influence over the small planets and asteroids that pass near them that *Jupiter* does over comets, the range of possible contingencies involves, on the one hand, closer and closer approaches and even collisions with the Sun and with other planets, and, on the other hand, the development of extremely elliptical orbits that will carry the small bodies into the sphere of influence of some other system. How large a proportion of these theoretical possibilities will be realized in a given disturbed system, it is impossible to determine, for the problem is far beyond the power of mathematical analysis, but it seems at least probable that results of moment may ensue.

If we may judge from the solar system, the small bodies may be assumed to be at least fifty times as numerous as the large ones, while not improbably they are a hundred or several hundred times as numerous. Other things being equal, they should show the characteristic effects of the action under discussion with correspondingly greater frequency. But the other conditions intensify these effects. A small body may be disrupted by a large one, but not necessarily the reverse. So, too, a small body may be thrown into an erratic orbit, while the orbit of the large body may not be sensibly affected, as shown by the changes in the orbits of comets caused by *Jupiter*. By far the most common effect of the close approach of two star systems should therefore be the fragmentation of the small bodies by being caused to pass within the spheres of disruption of the large bodies. As previously indicated, *the contingency of acquiring at the same time*

highly erratic orbits is imminent, and these are specially subject to still further changes, and thus these fragmental clusters come to possess by the very circumstances of their birth the second characteristic of comets, as well as the first.

Whether they would possess at the same time, or come at length to possess, the *third* characteristic of comets, the attenuated matter of which cometic tails are made, is not so clear, since the nature of this matter and its condition are not yet fully known. The recent discoveries relative to the extreme ionization of matter and perhaps even its corpuscular dissociation, and the radio-activity of certain kinds of matter are at least very suggestive in this connection. Six of the elements reported by good authority as detected in meteorites, are known to possess, or to be habitually associated with, radio-active matter, viz., barium, bismuth, cerium, lead, titanium, and uranium. It is not very material here whether this radio-activity is really possessed by all these elements themselves, or simply by substances associated with them. If the coma and tails of comets are dependent on rare substances of a radio-active or extremely volatile nature, and hence permanently retensible only in the interior of bodies, it would be difficult to imagine conditions more favorable for setting them free in unusual volume than minute tidal disruption; particularly is this true if the retention of these substances is dependent on low temperature, as seems to be the case, since they are brought forth and driven away at a highly accelerated rate as the sun is approached. This view seems also to be supported by the fact that comets which remain long in the vicinity of the sun, as for example the short-period comets, lose their tails in a brief period.

If the attenuated cometic matter owes its essential peculiarities to electric states, these might perhaps be derivable from the revolutionary movements of the magnetic elements in the fragmental swarm, for by the hypothesis of tidal disruption the swarm should inherit a rotatory movement, and the fragments should contain both magnetic and magnetizable matter, variously associated with diamagnetic matter.

That short-period comets are subject to progressive disintegration, and that their scattered elements constitute one class of meteorites, is familiar doctrine. There seems no reason for withholding the conception from comets which have parabolic or hyperbolic orbits, for in certain cases such comets have shown signs of disruption and partial dispersion in their perihelion passages. To the dispersed elements of these comets of high velocity is assigned (in part at least) such meteorites as come to earth from diverse directions with velocities incompatible with an origin within the solar system.

It remains to consider whether the fragments derived from the disruption of an asteroid, satellite, or small planet through differential gravitative strain without collision, will satisfy the characteristics which meteorites display. Ample data for a judgment on this vital point will be found in the articles on the structure of meteorites in the first two numbers of the *Journal of Geology* for the current year, by Dr. Farrington, who, at my request, has kindly brought together in succinct and systematic form the essential characteristics of meteoric structure. A study of these characteristics will show that, while they embrace a great and very significant variety, they are all referable to the structures that are appropriate to small planets, while it is difficult to see how all of these characteristics can be found in derivatives from any of the alternative sources to which meteorites have been assigned, namely, volcanic action of the moon or of the planets, explosive projection from the sun, or individual aggregation in space. Some of the matter is fragmentary, implying surface conditions, while some of it is coarsely crystalline, implying deep-seated conditions. Some is volatile and combustible, implying the absence of high temperature throughout its whole antecedent history, while some as distinctly implies the presence of high temperature. In some meteorites the iron is segregated, while in others it is disseminated. Frequent brecciated structures imply fracturing and recementation. *Faulting and slickensides* demonstrate movements attributable to the parent body, but not to the meteorite itself. Veins imply internal

transfer and redeposit of molecules. The absence of the oxidation of the iron accords with internal conditions, and also with the supposed absence of atmospheres from small planets, asteroids, and satellites. In short, every feature of the meteorites, save, of course, the external effects of fragmentation and of heating during their fall through the atmosphere, is assignable to small planetary bodies riven into fragments without great heat and, by reason of this, retaining the varied structure attained in the parent body.

As previously indicated, the disruption of a body like the earth, the main mass of which has a temperature much above the melting point of its substances at low pressures, and which is greatly compressed within by self-gravity, would doubtless cause it to burst forth into a luminous body with perhaps some dispersive violence. The progressive stages of distortion which take origin in simple tidal protuberances and grow to greater and greater degrees of deformation and crustal fissuring, until the final stage of disruption is reached, could scarcely fail to bring some parts of the ocean into contact with some parts of the heated interior, with inevitable Krakatoan consequences. Fragments of the crust under these conditions might possibly give origin to meteorites, but the probabilities of such fragments being projected beyond the 640,000 miles of the earth's dominant influence, or beyond the similar spheres of influence of other massive planets, would not seem to be great; and, if realized, the fragments would doubtless be reduced to dust, as in the case of the Krakatoan explosion, and this state of minute division would exclude such meteorites from recognition except as vanishing shooting stars. The probabilities are that the matter of a disrupted earth or a similar massive planet would be again assembled into a planetary body by its strong self-gravity. The phenomenon would therefore be that of a temporary star. Assuming considerable dispersion, it might be rather brilliant for a time, but would rapidly cool as the result of such dispersion, and soon sink into invisibility. In the case of such a body as *Jupiter*, accepting current doctrine as to his nature, the

initial brilliancy must be much greater and the cooling to invisibility much more prolonged.[1] To phenomena of this class may perhaps be tentatively assigned certain of the temporary stars. Obviously these can only be such as had no prior visibility, and such as sink sooner or later again into invisibility. Whether this invisibility were due to the superficial cooling of the nucleus, or merely to a deep enshrouding of cooled vapor, would be immaterial.

It has already been indicated that a possible result of the serious disturbance of one solar system by the near transit of another would be a fall of some of the disturbed planets upon one of the suns. This also might be an ulterior rather than an immediate result, through the modifying effects of other planets, as well as the direct effects of the primary disturbance. Such a fall must be presumed to give rise to a notable increase of heat in the central body, as well as to mechanical effects, both of which would be conditioned by the mass and velocity of the secondary. An outburst of greater or less brilliancy must be presumed to be the result. The mechanical effects upon the sun would probably involve great changes in temporary density and condition, as well as outshoots of hot gases in various directions at high velocities. The effects might thus coincide with the phenomena of that class of the temporary stars in which a luminous state precedes and follows the outburst, and in which varying densities or high velocities in opposite directions seem to attend the temporary brilliant stage.

The disruption of suns has been neglected thus far. While, under the terms of the hypothesis, the disruption of these bodies must be rarer events than the fragmentation of the more numerous small bodies, the results must be correspondingly more important, by reason of their magnitude and character.

It has already been observed, in passing, that the internal

[1] Such a body as *Jupiter* might perhaps, under proper conditions, be dispersed in the same manner as a sun as sketched beyond.

elasticity of large hot bodies under great self-gravitative compression may so far aid in disruption, by coöperation with the differential gravity of an adjacent body, as to cause dispersion even before the Roche limit is reached. In the case of very large bodies that are already gaseous, such as the sun, this phenomenon gives rise to a special case of extreme interest. Under this special case, there arise a large variety of particular instances due to the varying sizes, velocities, paths, rotations, and constitutions of the couplets of stars concerned, and also to the adventitious effects of their secondaries; but, for a simple illustrative case, let it be assumed that two bodies of equal masses and equal velocities are approaching each other on parabolic paths, and that at periastron they will pass through each other's spheres of disruption, or rather, spheres of dispersion. For convenience, let if be assumed that one of these bodies (A, Fig. 1) is gaseous, while the other (B) has already become so cold and solid as to act essentially as a unit, though disrupted. The history of the dispersion of the gaseous body may then be followed alone. Let the rate of rotation of the gaseous body (A) be relatively low, as in the case of our sun. It may then be neglected in a general discussion, since as a dynamic factor it is trivial compared with the enormous energies of momentum and of elastic dispersion involved. This will appear clear in the outcome. Furthermore, the direction of rotation with reference to the parabolic paths might happen to be any one of an indefinite number, in many of which the effect would be inconsequential, even if the energy were large. In the close approach of these two bodies the two great dynamic factors of special interest are (1) the tidal distortion, and (2) the elastic expansion of the gaseous body.

While the two bodies are yet distant from each other, they must begin to take on elongation of the tidal type as the result of their mutual differential attraction, this elongation being aided by the high internal mobility and elasticity of the gaseous body. As the bodies approach periastron, this elongation must progress at an accelerated rate. At the moment of the entrance of the

gaseous body *A* upon the Roche sphere of the body *B*, self-gravitation, in accordance with Roche's doctrine, will have been completely neutralized on the lines joining the centers of *A* and *B*, and its restraining influence upon the elasticity of the gaseous body on these lines will have been removed, while the gravitative constraint in the transverse section will be increased. The expansive energy of the compressed gaseous matter will therefore be left to exert its full projectile force in the direction of the axis of elongation. While I am unable to offer a numerical estimate of the magnitude of this expansional energy in such a body as the sun, it is certainly of a high order of magnitude. The speed at which prominences are projected from the sun under present conditions closely approximates to the parabolic velocity with respect to the sun, and this is accomplished in spite of gravitation and a resisting atmosphere.

The case in hand, therefore, starts with simple tidal elongation at a distance, and increases to an explosive maximum as the bodies approach periastron. This increase is at first gradual, but in the last stages of approach to periastron the acceleration is exceedingly rapid. In any attempt to follow the process in more detail, adhering to the recognized principles of tidal action, four particulars are of special moment: (1) the progressive elongation of the body, (2) the change in the direction of tidal distortion, (3) the lag of the line of maximum elongation behind the line of maximum attraction, and (4) the rotatory effects arising from the gravitation of *B* on the tidal protuberances of *A*, which in this case will be peculiarly effective because of the enormous distortion of *A* and the very close proximity of *B* at the critical stages. The principles from which these effects arise are thoroughly demonstrated and are familiar to all students of tidal phenomena, and it is only their special applications to this case that need be discussed. The rotatory effects are a little peculiar in that both of the tidally acting bodies are rapidly approaching each other, and developing extraordinarily powerful differential attractions, while at the same time they are swinging about their common center of gravity. Near periastron they

may be regarded as performing a semi-revolution about each other. By the terms of the special case in hand, this semi-revolution must be performed in a very few hours. During these few hours the gaseous body (A) is undergoing elongation at a rate not much less than that represented by its full explosive

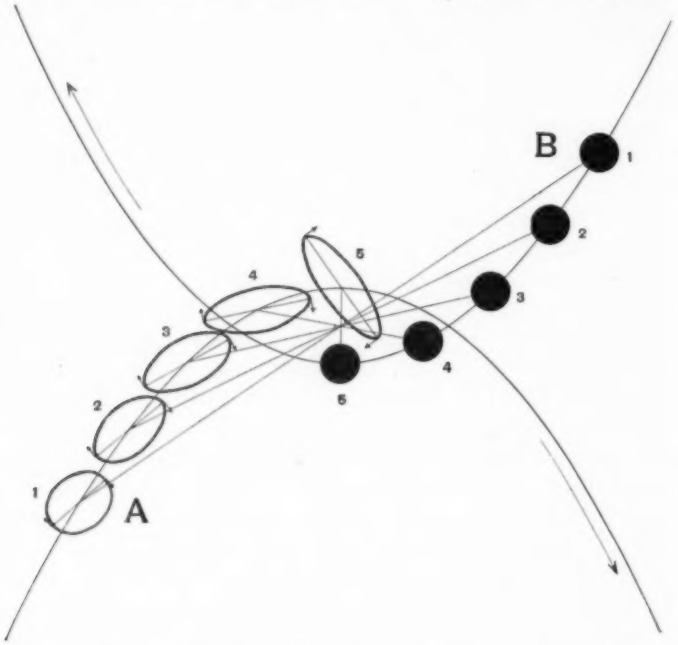


FIG. 1.—Diagram illustrating the elongating and rotatory effects of a solid stellar body, B, upon a gaseous sun, A, during their mutual approach to periastron. $A^{1, 2, 3, 4, 5}$ indicate successive positions, changes of form, and rotation of the gaseous star on its approach to periastron. $B^{1, 2, 3, 4, 5}$ represent the successive positions of a solid body of equal mass and velocity which is assumed for convenience to remain intact. Position A^1 corresponds to B^1, A^2 to B^2, etc. The lines joining their centers indicate the successive directions of mutual attraction. The arrows indicate direction of movement.

competency. The rotational forces are diagrammatically illustrated in Fig. 1, in which the lag is merely estimated and the distortion of A is simplified while that of B is neglected.

It is assumed that the lag of the axis of elongation of *A* is such that the effective path of explosive projection will be directed to the rear of *B*. It must be noticed that if the center of *A* passes through the outer part of the Roche sphere of *B*, the nearest edge of *A*, if undistorted, would pass within two or three hundred thousand miles of *B*, and hence that the projective elongation of *A* must pass critically near *B;* but the relative speed of the bodies *A* and *B* is so great—both being near the parabolic velocity with respect to the other—that the projected matter of *A* can only collide with *B* on the supposition that the velocity of projection at least equals the parabolic velocity of the body and acts instantaneously, the last of which is impossible. This is based on the assumption that the transverse component of the attraction of *B* prevents the elongation of the minor axis of *A*, which is true of liquid bodies tidally affected, but might perhaps break down in a gaseous body under these extraordinary conditions. The point, however, is not important here, for if the edge of the projected part of *A* collide with *B*, it will only intensify the rotatory effects under consideration, and such collision is contemplated as an essential feature of the next following case, but is excluded here as the effects of *approach without collision* is the special theme under discussion.

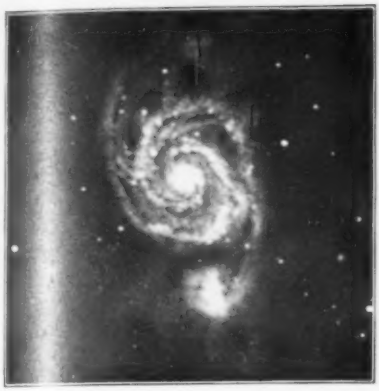
The very close approach of the elongated extremity of *A* to *B* obviously gives great effectiveness to the rotatory influence of *B*'s attraction upon it. If the amount of this attraction be represented by the fall of $\frac{1}{1000}$ part of the mass of *A* toward *B* at a mean distance of 200,000 miles from *B*'s surface—the masses of *A* and *B* being each equal to that of the sun—such a fall for about two hours and a half would generate a momentum equal to the whole revolutionary and rotatory momentum of the present solar system. It would appear, therefore, that under the conditions postulated a rotation of a highly effective kind must be imparted to the elongated body. It will now appear that the previous rotatory energy of the sun, which is only about 2 per cent. that of the solar system, is a negligible factor.

The history of *A* then takes this form: (1) A very rapid

elongation in the hour or two preceding its entrance upon the Roche sphere. (2) After entrance upon the Roche sphere, an explosive elongation actuated by the elastic energy then remaining in the body unrestrained by self-gravity in the axis of elongation. (A portion of the original elastic energy had been consumed in the previous elongation and a corresponding amount of momentum had been acquired, the larger component of which would be effective along the changed line of elongation.) (3) After passing out of the Roche sphere, the restraints of gravity begin again to be felt and rapidly increase as A and B retire from each other, but the distance to which the extremities of A have already been projected, and the new relations thereby assumed to the remaining mass of A, and to B, render the renewed gravitative influence far less effective than the original. and the projection must continue until the momentum acquired is overcome. (4) Coincident with this projection a constantly increasing rotation toward B has been generated, which possibly reached an effectiveness comparable to that of the solar system. *The effects of explosive projection combined with concurrent rotation must obviously give rise to a spiral form.*

It seems clear from the nature of the case that there would be a certain brief period when the climax of projective effects would be reached, and that a stream of material of much greater mass and velocity than at other instants would at this time be projected from the extremities of the elongated mass in both directions. There should therefore be two chief arms to the resulting spiral starting from the opposite points of the central mass and extending outward to the limits of the spiral — indeed constituting the most outlying portions of the spiral. These must be curved in a common direction by the rotation of the mass. Such predominant arms are notable features in the typical spiral nebulæ. They are well shown in Nos. 1, 2, 3, 4, 5, and 6, Plate I, all of which are reproductions from photographs furnished by the late Professor Keeler.

In the illustrative case that has just been discussed the solid body B was made to represent a convenient possible case but



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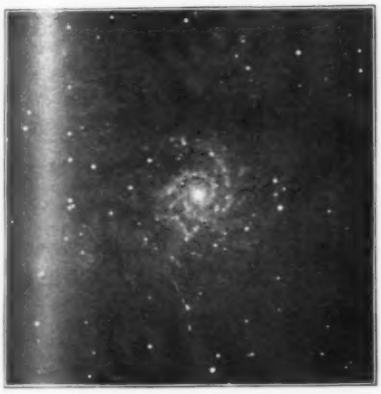

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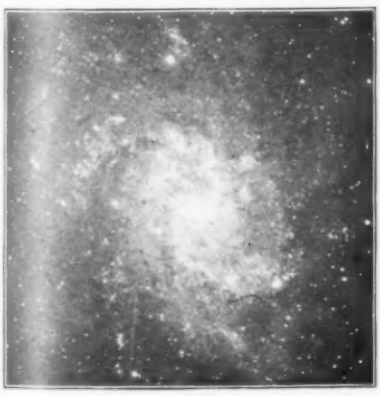

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6

SPIRAL NEBULAE

1. *M 51 Can. Ven.* = G. C. 3572–3574
2. *M 101 Urs. Maj.* = G. C. 3770—3771
3. *M 74 Piscium* = G. C. 372
4. *H IV 76 Cephei* = G. C. 4594
5. *H 33 Trianguli* = G. C. 352
6. *H I 53 Pegasi* and her nebula

one whose real frequency is quite unknown, since extinct suns are beyond the reach of observation. If the active lives of suns are no greater than the periods deduced from computations founded on the Helmholtz theory of solar heat, extinct suns should either be numerous, or the whole previous history of the stellar system must have been short; or else, as a *tertium quid*, some effective means of regeneration must be assumed.

In the more typical case of two live suns coming into such close relations, its seems probable that mutual dispersion might follow without serious collision, since the analysis of the phenomena seems to show that the mutual elongations of the live suns would develop on essentially parallel lines whose constant shiftings would be mutually consonant, as illustrated in Fig. 2. If no serious contacts were developed, the two resulting spirals would separate and pursue the paths normal to their parent stars, with such modifications as may have resulted from the loss of energy involved in giving rotation to the nebulæ.

If, however, the periastron approach is so close that partial collision ensues, the analysis seems to indicate that the elongated bodies which would be developed previous to contact would not collide end to end centrally, but by a lateral shear, as illustrated in Fig. 3. In this case the arrested momentum combines with mutual attraction to give a rotatory movement of the highest order, and the heat and the resilience from impact must combine to intensify the dispersive competency. The arrest of momentum may be presumed to go so far in some cases as to cause the two bodies to unite to form a single spiral nebula of the largest and most dispersed order, such perhaps as the well-known great spiral nebulæ; or the arrest may be partial, and certain parts of one or the other, or both, of the masses may escape. In No. 1, Plate I, we seem to have a possible example of this, in which the escaping, or partially escaping, mass [1] is still associated with the longest arm of the spiral.

[1] This is assumed to have been a dead sun because of the limited evidence of explosive action.

In case the collision of two suns becomes essentially central, a general dispersion of the most violent sort may be inferred to follow, and this may find exemplification in the vast irregular nebulæ, which are in many cases more or less radiant, and in some cases consist of two irregular masses which perhaps repre-

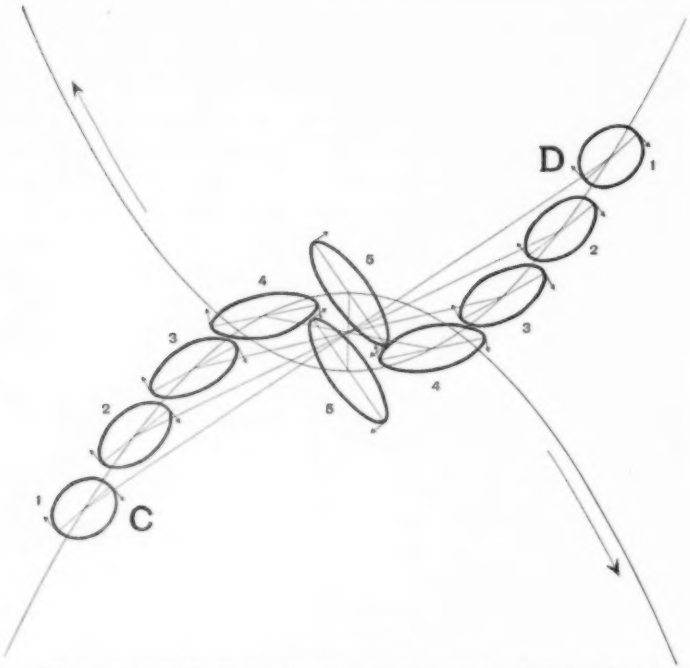

FIG. 2.—Diagram illustrating the progressive elongation and rotation of two suns, C and D, approaching perihelion. The position C^1 corresponds to D^1, C^2 to D^2, etc.; the lines joining these indicate the successive directions of mutual gravitation, and the arrows indicate direction of movement. The progressive elongation, the lag, and the rotation of the bodies at successive stages are diagrammatically indicated.

sent the wrecked originals. The collision of dead suns in which disruption shortly preceded actual impact may also play a part in forming irregular nebulæ.

Speculation may perhaps go so far as to attribute ring nebulæ

to the central penetration of a concentrated solid body through a gaseous mass.

It is as impossible as it is unnecessary to consider here the infinite variety of sub-cases which the hypothesis under consid-

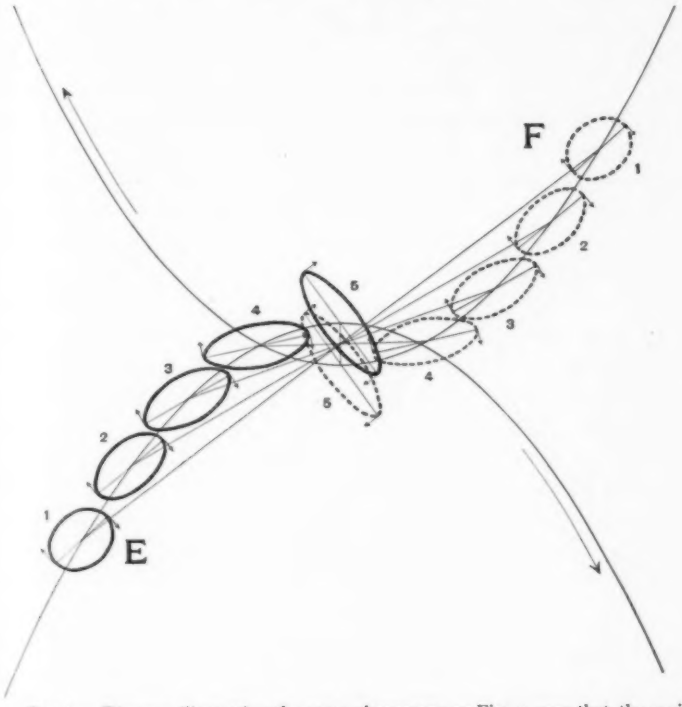

FIG. 3.— Diagram illustrating the same phenomena as Fig. 2, save that the periastron distance is so small that the bodies collide by a shearing stroke.

eration involves, but it seems advisable to note that the case of equal suns with equal velocities, which has been used in illustration, is not the most prevalent case; for inequality of mass and momentum is quite certainly the rule, rather than equality or sub-equality. Where one of the suns is much smaller than the other, the dispersive influence will be most largely felt by it,

and so it seems probable that there may be a series of cases in which the minor members of the couplets are dispersed with different intensities into complete nebulæ while the major members only suffer varying degrees of eruptive action or partial conversion into nebulæ and so perhaps become stars with nebulous adjuncts or atmospheres. Under this conception small nebulæ should be much more numerous than large ones. If large hot planets, such as Jupiter is supposed to be, are potentially gaseous, and if by disturbing approaches of stellar systems such planets are thrown out of their allegiance to their primary suns and take on comet-like courses, they would be specially liable to disruption and dispersion into small nebulæ, and would augment the number of the latter.

Whether the existing stellar movements and the mutual attractions of the stars are such as to give any substantial ground for believing that close approach can be a *chief* agency in producing comets, meteorites, and nebulæ, can only be determined when some approximate knowledge of the dispersion, the masses, the velocities, and the paths of the stars is gained. If the stars be considered simply as so many scattered bodies flying through space in straight lines at computed rates, and all mutual attractions and systematic relations be ignored, the frequency of disturbing approaches would not seem to be great and the quantitative value of the doctrine here sketched would seem to be questionable. The solar system has certainly never been subjected to disturbing approach since its present organization. But the assumptions made are certainly not the true ones and may not be representative. Besides the mere hazard of flying bodies, the mutual attraction of two stars after they enter upon each other's spheres of dominant influence — and these are very large — increases notably the probabilities of a disturbing approach even in the case of stars moving in opposed directions, while in the case of stars moving in sub-parallel and gently converging paths at sub-equal velocities, it may apparently become a dominant factor. At the average computed distances of the stars from each other, their mutual attractions are very slight, and

in the central portion of the stellar system, in which the sun seems to be placed at present, the general attractions are probably nearly balanced. Two stars, therefore, whose speeds are sub-equal and whose paths gently converge, may be controlled almost freely by their mutual attractions after they come within the spheres of each other's dominant influence. Such stars under mutual control would describe paths relative to each other similar to those assumed in the discussion. Their closeness of approach at periastron would be determined by the *relative differences* (not the total amounts) of their speeds and momenta. The principle of sub-parallel movements applies here and gives results quite at variance with those that obtain in cases of opposed movements, where the *relative sums* of the velocities and momenta are to be considered. The movements of the long-orbit comets seem to be concrete expressions of this principle, as their perihelia are largely clustered on the front side of the Sun, *i. e.*, the side toward which it is moving, and they make close approaches to it. Such star clusters as the *Pleiades*, the members of which seem to have proper movements nearly the same in amount and direction, are doubtless also expressions of the principle of sub-parallelism, and in their remarkable nebulosity they may at the same time illustrate the doctrine of disturbed secondaries leading on to dispersive action, a part of the product of which remains associated with the stars themselves, while a part is more or less widely scattered, as the terms of the doctrine require.

If our stellar system has a definite boundary and is a flattened spheroidal cluster or a discoid, and if the ideal paths of the stars are elongate orbits stretching from border to border across the heart of the cluster (except as diverted by close approaches), then the orbital speeds and momenta should be lowest on the outer surface, and the paths should there be most frequently sub-parallel, and hence the conditions for the close approach of two suns through their reciprocal attraction be there most favorable. Now, visible nebulæ are most frequent in the regions polar to the Milky Way, and they may be regarded as lying on

the flat sides or outer border of the stellar discoid where these conditions of low orbital velocity and momenta and prevalent sub-parallelism are dominant, and thus the distribution of nebulæ and the doctrine of close approach seem to be, so far at least, brought into harmony.

It may be needless to remark that the general conception lying back of the doctrine of dispersion by close approach has a complementary regenerative or reconstructive phase, which, taken with the dispersive phase, makes up a cyclic process. With the disruptive action there is correlated a reciprocal concentrative action, which is supposed to reproduce organized systems out of the wreckage of disrupted systems. The notion is further entertained that the two processes may be mutually self-adjustable, within the limits of general conditions, and thus may give a large degree of perpetuity to the existing phase of the stellar system.

T. C. CHAMBERLIN.

UNIVERSITY OF CHICAGO,
June 1901.

STUDIES FOR STUDENTS

THE CONSTITUENTS OF METEORITES. I

ELEMENTS

THE following elements have by good authorities been reported as detected in meteorites by means of chemical or spectroscopic examination:

Aluminum	Helium	Potassium
Antimony	Hydrogen	Selenium
Argon	Iodine	Silicon
Arsenic	Iron	Strontium
Barium	Lead	Sodium
Bismuth	Lithium	Sulphur
Calcium	Magnesium	Thallium
Carbon	Manganese	Tin
Cerium	Molybdenum	Titanium
Chlorine	Nickel	Tungsten
Chromium	Nitrogen	Uranium
Cobalt	Oxygen	Vanadium
Copper	Palladium	Zinc
Didymium	Phosphorus	

Many of these, however, occur only as traces, while others may possibly have been introduced by terrestrial agencies. The following list will be therefore more satisfactory as giving the primary and fundamental elements known to enter into the composition of meteorites:

Aluminum	Hydrogen	Phosphorus
Calcium	Iron	Potassium
Carbon	Magnesium	Silicon
Chlorine	Manganese	Sodium
Chromium	Nickel	Sulphur
Cobalt	Nitrogen	
Copper	Oxygen	

It will be of interest to compare the more important of these in

the order of their relative abundance, with the eight most important elements of the earth's crust placed in similar order. The list of the latter is taken from Roscoe and Schorlemmer.[1]

METEORIC SERIES	TERRESTRIAL SERIES
1. Iron	1. Oxygen
2. Oxygen	2. Silicon
3. Silicon	3. Aluminum
4. Magnesium	4. Iron
5. Nickel	5. Calcium
6. Sulphur	6. Magnesium
7. Calcium	7. Sodium
8. Aluminum	8. Potassium

It should be remembered in drawing conclusions from the above list that the elements of cosmic matter in its entirety are here compared with the elements of only the crust of the earth; further, that the meteoritic matter now known probably does not show a true proportion of stony matter. As I have shown elsewhere,[2] the iron meteorites are much more likely to be known and preserved than the stony. It is probable, therefore, that if the average composition of meteoritic matter were known, iron would not occupy so high a place as it does in the above table. The relative excess of magnesium and nickel, and scarcity of aluminum and calcium in meteoritic, as compared with terrestrial, matter may be due to the same cause.

COMPOUNDS

The elements of meteorites chiefly occur combined. The exceptions are iron, nickel, cobalt, and copper, all of which occur largely in the form of alloys, carbon, and the gases, hydrogen, and nitrogen, probably held as elements in the pores of meteorites.

The compounds of meteorites according to the mineralogical names by which they are generally known, and roughly in the order of their relative abundance, are as follows, the minerals not occurring upon the earth being printed in italics:

[1] Treatise on Chemistry, Vol. I. [2] Jour. Geol., Vol. V, p. 126.

ESSENTIAL	ACCESSORY
Nickel-iron	Included gases
Chrysolite	Iron sulphide
Orthorhombic pyroxene	*Schreibersite*
Monoclinic pyroxene	Graphite
Plagioclase	Cohenite
Maskelynite	Glass
	Chromite
	Amorphous carbon
	Diamond
	Daubreelite
	Tridymite
	Lawrencite
	Magnetite
	Oldhamite
	Hydro carbons

A brief account will be given of each of these.

Nickel-iron.—This is the most widely distributed constituent of meteorities and in quantity it exceeds all the others combined. It makes up practically the entire mass of all the iron meteorites, the larger part of the mass of the iron-stone meteorites and is found in nearly all, though not all, the stone meteorites. It is an alloy of iron and nickel in which the percentage of nickel varies from about 6 per cent. to about 20 per cent. Some iron masses claimed to be meteorites contain a higher percentage and some authorities regard the nickel-iron of most stone meteorites as generally containing from 20 to 40 per cent. of nickel, but this is somewhat uncertain. From 0.5 to 2 per cent. of cobalt always accompanies the nickel, as well as .006 to .02 per cent. of copper. Traces of manganese and tin are also often found. The terrestrial nickel-iron of the Greenland basalts differs from that of meteorites in having a lower percentage of nickel (0.25 to 4 per cent.) and in containing a considerable amount (3 per cent.) of carbon. The terrestrial nickel-irons known as awaruite and josephinite contain higher percentages of nickel than the meteoritic, the percentages being 67.7 per cent. and 30.5 per cent. respectively. In color, meteoritic nickel-iron varies from iron or steel-gray to silver-white, according to the percentage of

nickel present. In hardness and tenacity the nickel-iron of different meteorites varies greatly. That of some meteorites is harder than steel, that of others softer than wrought iron. That of some meteorites is so brittle as to break in pieces with a blow of the hammer, that of others so malleable that it can be worked into implements of various shapes. Nickel-iron is strongly magnetic and some iron meteorites exhibit polarity due perhaps to induction of the magnetism of the earth. The specific gravity of nickel-iron ranges between 7.6 and 7.9. It is dissolved at ordinary temperatures by the common acids, by solutions of copper sulphate, by copper chloride, by mercuric chloride, by bromine water, by copper ammonium chloride, and by a few other reagents. Some masses of nickel-iron when placed in neutral solutions of copper sulphate reduce the latter, while others do not. The former are known, according to the terms first used by Wöhler, as active, the latter as passive irons. Nickel-iron oxidizes rapidly when exposed to the atmosphere, the rapidity decreasing, however, with increase in the percentage of nickel. In regard to the manner of occurrence of the nickel-iron it may be noted that in the iron meteorites it forms a compact mass except in so far as it is interrupted by inclusions of other minerals. In the iron-stone meteorites all gradations occur from a continuous network to isolated grains. In the stone meteorites it is present in the latter form. A more or less lineal arrangement of these grains, recalling Widmanstätten figures, is often observed in the stone meteorites. When the substance occurs in grains, whether large or small, the shape of these is usually very uneven, being sometimes more or less rounded but generally irregularly branching. Sometimes regular forms such as cubes and octahedrons may be observed. In the Ochansk meteorite, von Siemaschko observed actual crystals made up of a combination of the cube, octahedron, dodecahedron, and a tetrahexahedron. Other cuboidal forms have been observed. The two or possibly three subordinate alloys (kamacite, taenite, and plessite) of which nickel-iron is composed have been described in a previous article and their composition given.

Chrysolite.—This is, next to nickel-iron, the chief mineral constituent of meteorites. It is found in all the iron-stone and nearly all the stone meteorites and makes up a large part of their mass. It occurs as crystals and as rounded and angular grains. In the group of iron-stone meteorites known as pallasites it is porphyritically developed in the nickel-iron; in other iron-stone meteorites it forms together with pyroxene a granular aggregate filling the meshes of a network of nickel-iron. In the chondritic meteorites the manner of its occurrence has already been described. Crystals occurring in cavities or isolated by dissolving adjacent nickel-iron lend themselves readily to goniometric measurement. A total of twenty forms, similar to those found on terrestrial chrysolite has thus been identified. The color of the mineral is usually the typical olive-green of terrestrial chrysolite but may vary to honey-yellow or red. Much of the meteoritic chrysolite is characterized by an abundance of opaque inclusions often regularly arranged. Intergrowths with a colorless to dark brown glass are also common, especially in the chrysolite of chondritic meteorites. Gas pores are rare. Alteration products so common to terrestrial chrysolite are entirely lacking. Much of the chrysolite shows a strong tendency to fissuring, especially in thin sections. Well-marked cleavage is not common. Numerous analyses of mechanically separated chrysolite show a composition similar to that of the terrestrial mineral. The percentage of Fe in these analyses shows variations from about 10 per cent. to about 30 per cent. One feature of the composition of meteoric chrysolite which seems at first difficult to account for, is an almost entire lack of nickel oxide. This, as is well known, is a very constant constituent of terrestrial chrysolite. Daubrée has shown, however, that an absence of nickel from meteoritic chrysolite should be expected, since nickel has less affinity for oxygen than iron and would not be attacked until the latter was completely oxidized. While terrestrial iron has been completely oxidized that of meteorites has not. The correctness of this explanation has further been shown experimentally by fusing terrestrial chrysolite with pyroxene in

the presence of a reducing agent. The nickel of the chrysolite then formed an alloy with the iron of the pyroxene. The siliceous portion of meteorites that is soluble in hydrochloric acid may for the most part be considered chrysolite, since numerous analyses of this portion give results corresponding in composition to this mineral.

Orthorhombic pyroxenes.—The minerals of this group are next in abundance to chrysolite as a constituent of meteorites. They form an essential part of nearly all stone meteorites and are not lacking in the iron-stone meteorites. At least four meteorites consist of orthorhombic pyroxenes alone. These are the meteorite of Bishopville, practically composed of enstatite alone, and those of Manegaon, Ibbenbühren and Shalka, which consist essentially of hypersthene. The color of the orthorhombic pyroxenes varies from colorless through white to various shades of green. Often the mineral has the typical color of chrysolite. In thin section the pyroxene is colorless to slightly colored. Its habit is usually prismatic but it may also occur as rounded grains. Crystals with well defined planes have been observed in the Breitenbach, Bustee, Manegaon and other meteorites. A total of thirty-two forms has thus been identified and the axial relations found to correspond with those of terrestrial hypersthene. Prismatic, macrodiagonal and brachydiagonal cleavages are recognizable. It is especially characteristic of the mineral to form eccentric, radiating, polysomatic chondri, the structure of which has been described in a previous article.

Numerous chemical analyses of mechanically separated orthorhombic pyroxenes have been made. These show all gradations between the compositions represented by the formulas $MgSiO_3$ (enstatite) (Mg, Fe) SiO_3 (bronzite) and (Fe, Mg) SiO_3 (hypersthene). The portion insoluble in acids, of meteorites consisting essentially of nickel-iron, chrysolite and orthorhombic pyroxenes, may be considered to be essentially the latter, as shown by numerous analyses which give results corresponding with the pyroxene formula. The orthorhombic

pyroxenes of meteorites are thus seen to be entirely comparable to the terrestrial minerals of the same name.

Monoclinic pyroxenes.— Two kinds of monoclinic pyroxenes have been identified in meteorites, the first bearing iron and alumina, the second free from alumina and nearly free from iron. The first may be considered similar to terrestrial augite, the second to terrestrial diopside. Augite has been identified in many meteorites, diopside positively only in one. Crystals of meteoritic augite have been measured goniometrically and eight forms similar to those of terrestrial augite found. As a rule, however, the augite occurs as grains or splinters. It varies from brown to green in color, in some meteorites is pleochroic in thin section in others not at all. Parting parallel to the base, owing to repeated twinning, is common and characteristic. It is sometimes regularly intergrown with orthorhombic pyroxene. Inclusions of glass and black dust are common. Pyroxene resembling diopside was identified by Maskelyne in the Bustee meteorite. It occurred in grains and splinters and was of a gray to violet color. A few goniometric measurements were possible. Analysis showed the composition to be that of a calcium-magnesium pyroxene. Crystals and grains from a few other meteorites may perhaps be referred to diopside but the determination is not certain.

Plagioclase.— Of the minerals of the feldspar group, anorthite may be mentioned as forming an essential constituent of the classes of stone meteorites known as eukrites and howardites and as occurring in others. It forms according to Rammelsberg about 35 per cent. of the stones of Juvinas and Stannern. Of the other members of the plagioclase series, albite, oligoclase and labradorite have been reported in single meteorites, but in most cases where plagioclase has been found the species has not been determined. Orthoclase has not yet been identified in any meteorite. Crystals of anthortite from the Jonzac meteorite reach a length of 1^{cm}. From the druses of the Juvinas meteorite anorthite crystals were obtained which served for goniometric measurement, eight forms being thus identified. Some

anorthite crystals show twinning according to the Carlsbad law and in the Llano del Inca and Dona Inez meteorites twins according to the albite and pericline laws were found. The mineral is sometimes white and sometimes colorless and in luster varies from dull to vitreous. Inclusions nearly always abound and they are generally regularly arranged. The inclusions are chiefly colorless glass, but sometimes brownish glass and opaque grains occur. Analyses of mechanically isolated anorthite have been made which show a composition similar to that of terrestrial anorthite. CaO amounts to about 18 per cent. in these analyses.

Calculating from analyses Tschermak concludes the feldspar of the stone of Gopalpur to be oligoclase, Lindstrom that of Hessle to be the same and Schilling that of Tennasilm to be labradorite. The presence of plagioclase other than anorthite has been proved by microscopical and chemical examination of other meteorites, but the species have rarely been determined. Such feldspars occur as lath-shaped individuals and as grains and splinters. Inclusions are much less common than in anorthite. Rounded, elongated inclusions referred by Tschermak to chrysolite and bronzite are, however, quite characteristic. Gas inclusions seem to be more abundant in the feldspars of meteorites than in any other constituent, though even here they are rare.

Maskelynite.—This is an isotropic, colorless, though becoming milky through alteration, transparent mineral of vitreous luster and conchoidal fracture. Its hardness is somewhat over 6; specific gravity 2.65. It has no cleavage but shows occasional irregular cracks and striæ similar to those of plagioclase. Inclusions of magnetite and augite are arranged in apparent zones. The mineral is slightly decomposed by hydrochloric acid. Thin splinters fuse, but with difficulty. Lath-shaped individuals with rectangular outlines occur, but in most meteorites the mineral is present as minute grains. It forms 22½ per cent. of the meteorite of Shergotty, the remainder of the meteorite being augite and magnetite. It is also an accessory constitutent in

the meteorites of Chateau Renard, Alfianello, Milena, Mocs, and others. Its composition is about that of labradorite. Tschermak regards the mineral as a fused feldspar, while Groth and Brezina consider it a distinct species allied to leucite. Its straight, sharply defined outlines, the existence of striæ, and the absence of any fused appearance make Tschermak's view difficult to accept, though the mineral resembles the feldspars in so many other respects.

Included gases.—All meteorites which have so far been tested give off on heating one or more of the following gases: Hydrogen, carbon monoxide, carbon dioxide, nitrogen, and marsh gas. Comparing the iron meteorites with the stone meteorites in regard to the kind of gases given off it is found that the former are characterized by a high content of H and CO, the latter by an excess of CO_2. The following table of analyses of gases from eight iron and six stone meteorites, quoted from Cohen, gives an idea of the relative quantity of each gas:

	H	CO	CO_2	N	CH_4
Iron meteorites	63.09	20.70	8.12	7.52	0.57
Stone meteorites	17.55	4.15	71.66	2.20	4.17

The volumes of the gases obtained vary from 0.97 of a volume given off from the iron of Shingle Springs to 47.13 volumes collected from the Magura iron. The average number of volumes obtained from the meteorites quoted in the above table is 2.82. The gases in meteorites appear therefore to be under a somewhat greater pressure than that of the earth's atmosphere. It has often been urged that the gases obtained from meteorites by the methods above mentioned may have been absorbed from our own atmosphere. It is known on the one hand that terrestrial rocks give off on treatment gases very similar in kind and quantity to those obtained from meteorites. Thus Wright obtained from one ordinary trap rock ¾ of a volume of gas, 13 per cent. of which was CO_2 and the remainder chiefly hydrogen, and from another, one volume of gas containing 24 per cent. CO_2 and the remainder chiefly hydrogen. Tilden has also recently shown that "the crystalline rocks of the surface of the earth contain very notable quantities

of gas, consisting of hydrogen in preponderance, carbon dioxide, and carbon monoxide in large percentage, and nitrogen and marsh gas in small quantities, with water vapor, but with a practical absence of oxygen. Twenty-five analyses including ancient and modern volcanic and even some metamorphic rocks gave an average volume of gas equal to about four and one half times the volumes of the containing rocks."[1] Further, it is urged that no meteorites have been analyzed as to their gases immediately after their fall. In contrast to these facts it should be noted that the Homestead meteorite was analyzed for gases by Wright within three months from the time of its fall. A second analysis was made a year later in order to test the influence of the earth's atmosphere upon the stone. It was found that very little change had taken place except a slight *loss* of carbonic acid. Ansdell and Dewar in testing the gases of the Pultusk and Mocs meteorites chose stones of those falls which were completely incrusted so that the chances of absorption of gases from the earth's atmosphere might be reduced to a minimum. Yet the results obtained accorded well with those from other meteoric stones and for Pultusk the percentages were remarkably like those derived by Wright in a previous and independent examination of stones of the same fall. There seems, therefore, good reason to believe that the gases obtained from meteorites are brought with them from space and that they have not been derived from the earth's atmosphere.

How the gases are held by the meteorites is uncertain. Wright was inclined to believe that the pores occasionally noted in the silicates of meteorites indicated cavities where the gas was held. Such pores are of too rare occurrence, however, to meet the demands of the problem. The phenomenon seems more like the occlusion of hydrogen by platinum or zinc, and the gases are probably held partly in the intermolecular spaces and partly chemically united. Travers, however, regards them as produced by heat from the non-gaseous elements of the

[1] T. C. CHAMBERLIN: JOUR. GEOL., Vol. VII, p. 558. Quoted from Chemical News, April 9, 1897.

meteorites.[1] The magnetic and nonmagnetic or, in other words, the metallic and stony portions of the Homestead meteorite were tested separately by Wright in order to determine whether these different portions exercised any selective action in holding gases. The investigation gave the following results:

	Volumes	H	$CO+CO_2$	N
Entire stone	1.87	50.93	48.07	1.00
Magnetic portion, 0.51	1.48	59.38	38.72	1.90
Non-magnetic portion, 0.97		30.96	66.96	2 08

The results show no important differences in the gases held by the different portions. By way of caution, attention should be called to the fact that the gases in meteorites may not have been originally present in the form and quantities which the analyses indicate. Thus Wright in making his analyses found CO_2 rapidly reduced to CO through contact with heated iron. Likewise, H, CO, and iron may at a moderate heat reduce the iron oxide present in many meteorites, and thus the character of each be changed. The percentages of the different gases obtained by analyses may be, therefore, more indicative than absolute.

Cohen calls attention to the fact that from artificial irons may be obtained gases corresponding both qualitatively and quantitatively to those obtained from meteoric irons. The following list of analyses illustrates this.

	H	CO	CO_2	N
White, carbonaceous cast iron	74.07	16.76	3.59	5.58
Mild steel	52.6	24.3	16.55	6.5
Ordinary gray massive charcoal iron	38.60	49.20		12.20
Gray coke iron	32.70	57.90		8.40
Steel	22.27	63.65	2.27	11.36

Finally it should be noted that, according to the investigations of Vogel, Wright, and Lockyer, the spectra of the gases obtained from meteorites show remarkable resemblances to the spectra of comets.

[1] Proc. Roy. Soc., Vol. LXIV, pp. 130–142.

Iron sulphide.—Troilite-pyrrhotite.—The exact form and composition of the iron sulphide which is a common ingredient in meteorites is a question not yet satisfactorily answered. For convenience, Rose's assumption that the iron sulphide of iron meteorites is troilite, that of stone meteorites pyrrhotite, is usually followed, but there are many occurrences which do not harmonize with this view.

The iron sulphide known as troilite is usually found massive, though crystals have been observed which have been referred by Brezina to the hexagonal and by Linck to the isometric system. The color varies from bronze-yellow to tomback-brown. Streak black. Hardness, 4. Specific gravity, 4.68–4.82. Generally found to be non-magnetic, although magnetic troilite has been reported. Cohen suggests that the magnetism may be due to included nickel-iron. The mineral fuses in the reducing flame to a black, magnetic globule. Decomposed by hydrochloric acid with evolution of hydrogen sulphide, but without separation of sulphur. Not affected by copper sulphate or fuming nitric acid. These reagents may be used, therefore, for its separation.

Most analyses show a composition approximating very closely to FeS. Meunier, however, obtained results more nearly in accord with the formula $Fe_{11}S_{12}$. As this is the composition of pyrrhotite he regards the two as identical. The specific gravities which he obtained, however, correspond to those observed by others for troilite, and there seems therefore, some reason to doubt the correctness of his analysis.

Troilite is almost universally present in the iron meteorites. It may be very unequally distributed in a single mass, however, being abundant in some portions and lacking in others. It usually occurs in the form of nodules, but also as plates and lamellae. The nodules vary greatly in shape and size. Rounded and oval forms are common, as are also lens and dumb-bell shapes. In Carlton a star-like form occurs. Smith separated from the Cosby's Creek iron a nodule weighing 200 grams, while one from the Magura iron measured 13^{cm} in diameter. When troilite occurs as lamellae, these are often regularly

arranged parallel to the planes of a cube. Lamellae having this arrangement are known as Reichenbach lamellae. Individual lamellae of this sort average from 0.1–0.2^{mm} in width and 1½–3½^{cm} in length. They cross layers of kamacite, and hence must have formed before these. Troilite often occurs intergrown with schreibersite and graphite, and these sometimes surround it. It also often includes nickel-iron.

The fusion and dissipation of troilite nodules during the passage of a meteorite through the atmosphere is a cause of the depressions often to be observed on the surface of both iron and stone meteorites.

The iron sulphide of the stone meteorites occurs chiefly as grains, sometimes as plates, and sometimes in vein-like forms. As mentioned in a previous article, it also occurs in chondri, frequently forming their periphery, while at other times it is in the form of grains. Crystals from the druses of the Juvinas meteorite measured by Rose proved to be hexagonal and to have forms similar to those of terrestrial pyrrhotite. It is largely on account of these observations that the iron sulphide of stone meteorites is considered to be pyrrhotite. On the other hand, the iron sulphide of stone meteorites differs from pyrrhotite in being, for the most part, non-magnetic, and in giving no free sulphur on decomposition with hydrochloric acid. Further, most analyses show a composition corresponding to the formula Fe S.

Schreibersite.—This mineral, peculiar to meteorites (if its possible occurrence in the terrestrial iron of Greenland be excepted) is also one of their most remarkable constituents, since it gives proof that the meteorites in which it occurs could not have been exposed for any long time to the action of free oxygen. The mineral is a phosphide of iron, nickel, and cobalt, having the general formula $(Fe, Ni, Co)_3 P$, though the relative proportions of the metals vary. The normal color is tin-white, but this may readily alter to bronze-yellow or steel-gray on exposure to the air. Hardness 6.5, specific gravity 6.3–7.28. Strongly magnetic, and when magnetized retains its magnetism

for a long time. Very brittle, being thus distinguished from taenite, with which it is often confounded. Another property which distinguishes it from taenite and from cohenite is that it is insoluble in copper-ammonium chloride. It is soluble in ordinary dilute acids and in acetic acid. Does not reduce copper from a copper sulphate solution. Easily fusible before the blowpipe to a magnetic globule. It occurs as crystals, flakes, foliae, grains, and as needles. In the latter form it was long regarded a separate mineral, and was known under the name of rhabdite, but the identity of rhabdite and schreibersite has been proved by Cohen. The needles and plates often exhibit angular outlines. Individual masses of the mineral often reach a considerable size, one from the Carlton iron being 14 cm. in length. The mineral also forms a considerable portion of the mass of some meteorites, such as Bella Roca, Primitiva, and Tombigbee River. It is the most widely distributed constituent of iron meteorites, aside from nickel iron, and is believed to be usually associated with the latter mineral in the stone meteorites, though its quantity is so small that it has not often been determined. The small percentage of phosphorus usually found in the analysis of stone meteorites is generally referred to this mineral. Schreibersite has been reported in the terrestrial iron of Greenland, but its presence is not proved. Phosphides similar to schreibersite have been made in several ways artificially. The process followed has been essentially to heat iron to a high temperature together with a phosphorus-bearing compound.

Graphite.—This substance occurs in grains of sufficient size for ready examination only in the meteoric irons. In these it is usually in the form of nodules but sometimes occurs in plates or grains. The nodules often reach considerable size. One nodule taken from the Cosby's Creek iron is as large as an ordinary pear and weighs 92 grams. Even larger ones were found in the Magura iron. Toluca, Cranbourne, Chulafinnee and Mazapil are other irons which contain considerable graphite. Graphite has been estimated to form 1.17 per cent. of the mass of

Magura and 0.8 per cent. of the Cosby's Creek iron. The mineral is usually associated with iron sulphide. With this it may be intimately intergrown or the one may enclose the other. Its texture is compact rather than foliated. Smith found that the meteoric graphite oxidized much more rapidly than terrestrial graphite on treatment with nitric acid and chlorate of potash. This feature distinguishes it from the amorphous carbon separated from cast iron. The meteoritic graphite is also very pure. Although occurring in nodules of the size described, which must have segregated from the surrounding mass, the ash amounted, in an analysis made by Smith, to only 1 per cent. By ether was extracted a small quantity of a substance made up of sulphur and a hydro-carbon, which constituted the only other impurity. Emphasizing the differences between meteoritic and terrestrial graphite Smith was inclined to believe that the graphite of meteorites must have been formed by the action of bi-sulphide of carbon upon incandescent iron rather than that it was analogous in its origin to terrestrial graphite. Ansdell and Dewar, however, concluded from elaborate comparisons of meteoric and terrestrial graphite that they were similar in origin, and were formed by the action of water, gases and other agents on metal carbides. Whatever its mode of formation the occurrence of graphite in meteorites is of geological interest as proving that graphite may be formed in nature without the agency of life.

Cohenite.—This is a carbide of iron, nickel and cobalt. It has been positively identified in only a few meteorites but is doubtless of common occurrence. Its formula is $(Fe, Ni, Co)_3 C$. The mineral is of metallic luster and tin-white color, though readily tarnishing to bronze-yellow. Hardness, 5.5–6. Specific gravity, 7.23–7.24. Strongly magnetic; very brittle. Insoluble in dilute hydrochloric acid and decomposed by concentrated hydrochloric acid only with difficulty. Easily soluble in copper-ammonium chloride. It occurs as isolated crystals on which several forms of the isometric system have been noted; also as grains. Elongated crystals, reaching a length of 8 mm are

found in the Magura meteorite. These are arranged parallel to octahedral planes. An iron carbide similar to cohenite is formed in cast iron when the latter is heated to a temperature of 600–700° C. and slowly cooled. Cohenite occurs in the terrestrial iron of Niakornak, Greenland.

OLIVER C. FARRINGTON.

(To be continued.)

THE PALEOZOIC FORMATIONS OF ALLEGANY COUNTY, MARYLAND[1]

INTRODUCTION

THE author of this paper has been engaged since the summer of 1897 as chief of the Division of Appalachian Geology of the Maryland Geological Survey in studying the geological formations of the western counties of Maryland. He has had as assistants in this work at different times Messrs. C. C. O'Harra, R. B. Rowe, G. C. Martin, A. C. McLaughlin, and A. P. Romine. Mr. Richard B. Rowe, who was already acquainted with the New York formations, reached the conclusion, as the result of his field work during 1897, that several of the Paleozoic formations of western Maryland could be correlated with those of New York. The continuation of Mr. Rowe's work, together with that of Mr. Romine, under my direction during the field seasons of 1898, 1899, and 1900 further confirmed these views.

The following account of the Paleozoic formations of Allegany county, Maryland, embraces a brief description of their character and distribution, together with a statement regarding their probable correlation with the New York and Pennsylvania formations. The report of Dr. C. C. O'Harra on "The Geology of Allegany County"[2] incorporated the revised classification of western Maryland devised by Dr. William B. Clark, the writer, and his assistants, and thus represents the conclusions, based on the field work carried on during the seasons of 1897–1900. The writer is under obligations to Professor Bailey Willis, whose manuscript on "The Appalachian Region—Paleozoic Appalachia, or the History of Maryland during Paleozoic Time,"[3] was

[1] Published by permission of Dr. William Bullock Clark, state geologist of Maryland.

[2] Md. Geol. Survey, Allegany county, 1900, pp. 57–163.

[3] Maryland Geol. Survey, Vol. IV, 1900, pp. 23–93.

kindly placed at his disposal, and has recently been published under the auspices of the state survey.

THICKNESS

The strata covering Allegany county have a thickness varying from about 13,300 to 16,000 feet. This thickness is divided between the four geological systems represented in the county in the following manner: Silurian, from 2200 to 2400 feet; Devonian, 7875 to 10,200 feet; Carboniferous, 2825 to 3000 feet, and Permian (?), about 400 feet.

SILURIAN STRATA

Juniata formation.—The oldest rocks outcropping in Allegany county belong in this formation, and are shown in only one locality. This outcrop forms the lower part of the cliffs in the gorge known as "the Narrows" just northwest of Cumberland, where Wills Creek has cut a deep and narrow trench through Wills Mountain. This gorge presents an admirable example of a narrow transverse valley where a stream has cut through a mountain ridge, and this locality has a justly deserved reputation for great natural beauty. The upper 370 feet of the formation is well shown on the northern side of the creek; but in many places in the gorge it is concealed for the most part by heavy talus of white quartzite blocks from the cliff above. In the Narrows 550 feet of the Juniata are shown, but no fossils have been found at this locality. The formation is composed of alternating beds of deep red shales and sandstones which have no regularity of succession, but show a much greater total thickness of shales than sandstones. The sandstones are hard, fine-grained, cross-bedded, and micaceous, some of the strata a foot or more in thickness, but usually less than six inches. The shales are micaceous, weathering readily, and the beds vary from an inch to six feet or more in thickness. This formation was named from the Juniata River, Pa., though in the earlier reports of that state it was termed the Medina or Levant red sandstone (No. IV*b*). It probably represents the older part of the Medina

stage of New York near the base of the Upper Silurian, which, in western New York, is composed mainly of red shales.

Tuscarora formation.—This quartzitic sandstone, which rests conformably upon the Juniata formation, and forms the beautiful flat-topped arch of Wills Mountain is admirably shown on its western side, especially at the entrance to the Narrows, and in the upper part of the high massive cliffs bordering the gorge. It also forms the greater part of the exposed rocks in Evitt's and Tussey's mountains and two small areas along the Baltimore and Ohio Railroad near Potomac Station. The formation is a white to light gray, very hard quartzose sandstone composed of fairly coarse quartz grains cemented by siliceous material. Small pebbles of quartz and also those of yellowish-green hard clay occasionally occur. The layers are frequently very massive and cross-bedded structure is not infrequent. Its thickness varies from 250 to 300 feet, and it furnishes building stone and ballast. *Arthrophycus harlani*, a sea-weed, the only fossil found in this sandstone in the county is fairly common on the upper surfaces of the higher beds in the Narrows.

The Tuscarora formation, named from Tuscarora Mountain in Pennsylvania, was formerly called the Medina or Levant white sandstone (No. IV*c*), and represents the upper part of the Medina stage of New York. The Juniata and Tuscarora formations are probably equivalent to the Medina formation of New York, but in western New York, where it is typically represented, especially in the Niagara region, there is not such a definite separation into a lower divison composed of red shales and sandstones and an upper one composed of a white quartzose sandstone as in Maryland. In the Niagara region the Medina is composed of the following divisions named in ascending order: Lower Medina, composed of red shales only about the upper 115 feet of which is exposed in outcrop. Upper Medina, composed of seven zones: (1) 25 feet of gray quartzose sandstone; (2) 25 feet of thin gray shales; (3) five feet of gray sandstones and sandy shales; (4) 6 feet of mainly gray argillaceous shales which become reddish at the top; (5) 35 to 40 feet

of mainly thin-bedded sandstone reddish in color or gray mottled with red; (6) 12 to 15 feet of massive sandstone in beds from one to several feet in thickness and varying in color from reddish to grayish; (7) at the top 7½ feet of a hard massive-bedded and compact white quartzose sandstone similar to No. 1. In some thin sandstones in the upper part of No. 6 occurs the characteristic Medina fossil known as *Arthrophycus harlani* (Conrad).[1]

Clinton formation.—The largest area of this formation flanks both sides of Wills Mountain extending to the Potomac River, while two other areas flank the southern ends of Evitt's and Tussey's mountains. The formation is composed largely of yellowish-green to reddish shales, but on weathering, the flat surfaces frequently have a scarlet tint. There are blackish shales and thin fossiliferous limestones in its upper part as well as a greenish-gray to reddish sandstone. The most important lithologic character of the formation, however, is the two beds of iron ore, the lower occurring from 120 to 160 feet above its base and consisting of two strata of iron ore separated by a band of greenish-yellow shales from 6 inches to 6 feet thick. The two ore-bearing strata have a thickness of from 10 to 12 feet. At Cumberland the upper bed of iron ore is 270 feet above the lower one, in the midst of a brownish, calcareous sandstone, nearly 3 feet thick which is directly above a massive 5-foot sandstone stratum. There are 9 inches of quite clear, fossiliferous iron ore and the overlying greenish shales and thin bands of bluish limestone also contain fossils. The thickness of the formation varies from 550 to 600 feet. Fossils are common in the middle and upper portions, some of the species being identical with those of the New York Clinton. The name is derived from the exposures at Clinton, Oneida county, N. Y., where the beds of iron ore have been mined for many years, and the stage is identical with No. V*a* of the Pennsylvania survey which is

[1] For an excellent account of the Medina formation along the Niagara River, see Bull. N. Y. State Museum, No. 45, 1901, pp. 87–95 and accompanying geological map by Dr. Amadeus W. Grabau.

called the Rockwood formation in the Piedmont folio of the U. S. Geological Survey.

Niagara formation.—This formation surrounds the three areas mentioned under the Clinton formation. The lower part consists of thin-bedded, blue limestones with thin shale partings; but in the upper part the shales predominate and become blackish in color. The thickness varies from less than 250 to fully 300 feet. The thin limestones contain brachiopods and other fossils, some of which are specifically identical with the Niagara fossils. The formation is named from the admirable exposures at Niagara Falls and represents No. V*b* of the Pennsylvania survey and the lower part of the Lewistown formation of the Piedmont folio. The revised classification of the New York series by Messrs. Clarke and Schuchert, however, drops the Niagara formation or group and returns to the earlier classification of Rochester shale, Lockport limestone, and Guelph dolomite.[1]

There has been more or less uncertainty regarding the identification of the Niagara limestone south of New York; but recently Dr. Weller has conclusively shown that the Decker Ferry formation of western New Jersey and eastern Pennsylvania is of the same age "as the Rochester shale and Lockport limestone of Clarke and Schuchert, or as the Niagara formation of most authors."[2] A small collection of fossils from the beds near Cumberland was submitted to Dr. Weller who kindly examined them and wrote that his impression is that they are the same as the Decker Ferry formation, and in New Jersey there are sufficient authentic Niagaran species to definitely refer the formation to the Niagaran. In conclusion he stated that "I should think you would be fully justified in considering the Cumberland fauna as of Niagaran age."[3] Mr. Schuchert has studied these beds in the field as well as their fossils and he positively correlates them with the Niagara. His statement is that

[1] Science, N. S., Vol. X, 1899, p. 876.

[2] Geol. Surv. N. J., Ann. Rept. for 1899–1900, p. 18, and also see p. 20.

[3] Letter of May 29, 1901.

"there are beds at Cumberland, Md., holding a fauna of the age between the Lockport [Rochester?] shale and the Guelph of New York and Ontario. This fauna has its peculiarities, but the aspect is certainly not Clinton."[1]

Salina formation.—This formation borders the Niagara but the rocks are largely concealed over most of the areas except along Wills Creek in Cumberland, Flintstone Creek at Flintstone, and the Baltimore and Ohio Railroad near Potomac Station, where one finds the best exposure. In the Potomac section there are four cement beds which have great economic value, the lowest one situated about twenty-five feet above the base of the formation. Fifty feet of the succeeding 140 feet of the formation is composed of the four cement beds which are separated by shales and impure limestones. Succeeding the upper cement bed are 450 feet or more of gray shales, drab and blue limestones and sandstone, the limestones predominating.[2] The thickness is about 700 feet. Fossils are not common. The formation was named from Salina in central New York and is represented by No. V_c of the Pennsylvania survey and the second part of the Lewistown formation of the Piedmont folio.

The statement has been made that "the geological reader will wonder on what basis the name Salina is applied to the rocks so described" in Maryland.[3] It is perhaps sufficient to state that Professor Lesley, the former state geologist of Pennsylvania and admirable stratigraphical geologist, correlated the corresponding rocks of Pennsylvania with the Salina. In Bedford county, Pennsylvania, which lies immediately north of the Cumberland region, Professor Lesley gave the upper and middle divisions of the Salina as 628 feet in thickness to which is to be added a portion of the 472 feet composing the lower Salina

[1] Letter of June 26, 1901.

[2] Mr. Schuchert has recently studied this formation in the Cumberland region and he writes me as follows: "I am inclined to cut out of the Salina the lower 23' 6" as given on p. 93 of O'Harra's report (Maryland Geological Survey, Allegany county). This thickness I now refer to the rest of the Niagara. I also extend the Salina a little higher, making the total thickness 704'." (Letter of June 26, 1901.)

[3] Am. Jour. Sci., 4th ser., Vol. XI, p. 240, 1901.

which included the Niagara beds at its bottom.[1] Mr. Schuchert also fully concurs in correlating these Maryland beds with the Salina.

DEVONIAN STRATA[2]

Helderberg limestone.— The largest area covered by this formation is in the central part of the county which it enters to the north of Flintstone and then runs in a zigzag manner back and forth until it leaves the county on the western side of Evitt's Mountain. Another area follows Shriver Ridge and passes through western Cumberland across the county. A third area enters in the eastern part of Wills Creek valley and runs across the county, keeping west of Wills Mountain, to Potomac Station; and, finally, to the southwest is the Fort Hill area, beween Rawlings and Dawson. The best localities for studying this formation are the Devil's Backbone, northwest of Cumberland; the cliff on the West Virginia side at Cedar Cliff and the Baltimore and Ohio Railroad cut near Potomac Station. The lower 400 feet of the formation is composed of fairly thin-bedded bluish-gray limestones, separate pieces of which have a metallic ring when sharply hit. The more shaly layers contain fossils among which are *Tentaculites gyracanthus* and *Spirifer vanuxemi*, characteristic species of the Tentaculite limestone in New York with which this zone is correlated.

Messrs. Clarke and Schuchert in their revised classification revived Vanuxem's geographical name of Manlius limestone for the paleontological one of Tentaculite limestone.[3] The Maryland zone was put in the Helderbergian instead of the Cayugan period because, as clearly stated by Dr. O'Harra, "the lithological break between it and the Salina is very marked and can be followed in the field . . . . while there is no lithological break between the Tentaculite and Lower Pentamerus subformations, and the division for mapping purposes cannot be made here."[4]

[1] Summary Description Geol. Pennsylvania, Vol. II, p. 839, 1892.

[2] The Geological Survey of Maryland has followed Dr. Clarke and Mr. Schuchert in referring the Helderbergian period to the Devonian system.

[3] Science, N. S., Vol. X, pp. 876, 877, 1899. [4] Allegany county, p. 96.

Higher in the formation are massive darker blue limestones, about 240 feet in thickness according to Schuchert or from 50 to 150 feet as given in Rowe's report, some of the layers of which contain numerous specimens of *Pentamerus* (*Sieberella*) *galeatus*. This zone probably represents the Lower Pentamerus limestone of New York, of which the above fossil is a characteristic species.

In place of the paleontological name Lower Pentamerus limestone, Messrs. Clarke and Schuchert proposed Coeymans limestone.[1]

In the upper fifty feet or more of the limestones are frequent specimens of *Spirifer macropleurus* characteristic of the Delthyris shaly limestone of New York, with which this zone is correlated. In New York this division of the Helderberg consists of calcareous shales and shaly limestones with some beds a foot or more in thickness, but in Maryland it is composed mainly of fairly massive limestone. With the exception of the Lower Pentamerus, all the Helderberg limestones are more massive in Maryland than in New York. In place of the term Catskill or Delthyris shaly limestone Messrs. Clarke and Schuchert proposed the geographic name of New Scotland beds.[2]

The Becraft limestone, which caps the Helderberg limestone of New York, is apparently not represented in Allegany county, although some eighty-five feet of it occurs farther east in Washington county, Md.

The thickness of the foundation varies from 750 to 900 feet, and fossils are common in some of the layers. The limestones are valuable for quicklime, ballast, road-metal, and building purposes. The formation is named from the lower limestones of the Helderberg Mountains in eastern New York, and is the equivalent of No. VI of the Pennsylvania survey, and the upper part of the Lewistown formation of the Piedmont folio.

Oriskany sandstone.—The easternmost area of Oriskany sandstone is that of Stratford Ridge, to the northeast of Oldtown; then follows that of the central part of the county bordering

[1] Science, N. S., Vol. X, pp. 876, 877. [2] *Ibid.*, pp. 876, 877.

the zigzag Helderberg area; then, in order named, that crossing the county along the eastern side of Shriver Ridge; the narrow band extending across the county to the west of the Helderberg area west of Wills Mountain; to the southwest the band on the western side of Fort Hill, and, lastly, the area extending from the Twenty-first Bridge to Monster Rock at Keyser.

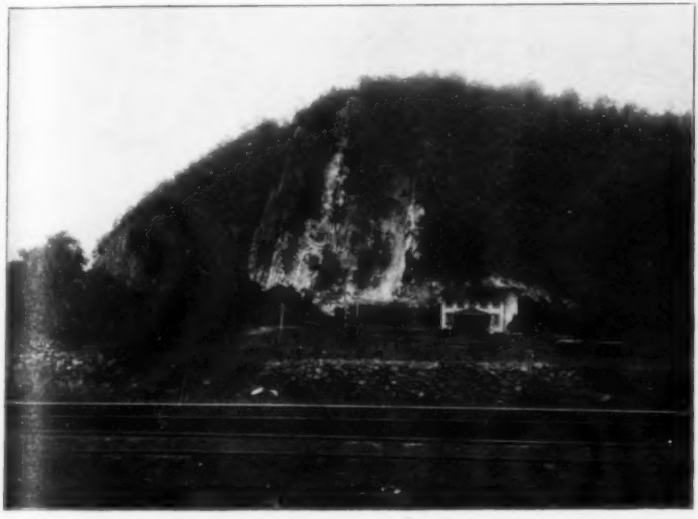

FIG. 1.—Devil's Backbone, near Cumberland, showing Helderberg limestone in the steeper part and Oriskany sandstone in the farther railroad cut.

The lower part of the formation is mainly a bluish-black cherty limestone, 75 to 100 feet in thickness, the chert in nodules and layers, with some dark gray arenaceous shales; and the remainder of the formation is mostly a sandstone, frequently calcareous, and varying in color from gray to white, about 250 feet in thickness. Toward the top there are a few bands varying from grit to conglomerate. The sandstone, on account of its calcareous cement, weathers readily to a friable brownish or buff, porous rock, which, when protected from erosion eventually forms beds of sand. Its thickness varies

from 325 to 350 feet. It furnishes railroad ballast and good glass sand. Fossils occur abundantly in zones varying in thickness from an inch to several feet. The most perfect specimens may be obtained from the beds of sand from the disintegrated rock, and frequently from pockets of sand in the partly weathered rock. *Spirifer arenosus* and other common species of the formation in New York are abundant, together with species which are restricted to its southern distribution. There are numerous springs along the contact of the Helderberg and the Oriskany sandstone. The formation is named from outcrops near Oriskany Falls, in central New York; is known as No. VII in Pennsylvania; and is the Monterey sandstone of the Piedmont folio.

Romney formation.—This formation enters the county on the eastern side of Iron Ore Ridge, northeast of Flintstone, crosses it and covers a large area to the east, north, and west of Oldtown, then alternates with the Oriskany areas in the southern central part of the county, and finally crosses in a V-shaped area—the eastern arm west of Nicholas Mountain, the point along Evitt's Creek, and the western arm passing through the eastern part of Cumberland. The western area enters the county at Ellerslie, crosses it to the Potomac River, and then extends southwest to the bend in the river at Keyser, W. Va.

The transition from the Oriskany sandsone to the black shale of the Romney is very abrupt, as may be seen at various exposures of the contact, especially east of the church on the Williams Road, two and one half miles southeast of Cumberland, and at Monster Rock on the W. Va. Central Railroad, near Keyser, W. Va. The lower part of the formation is composed of thin black shales, weathering to a rusty brown, in which are some bands of bluish-gray limestone about 150 feet above the base. This portion of the formation is well shown in the two railroad cuts just north of the Twenty-first Bridge on the Baltimore and Ohio Railroad. The black shales contain specimens of *Liorhynchus limitaris* and other small fossils, and in lithological characters agree with Marcellus shale of New York or No.

VIII*b* of Pennsylvania, which they represent. The higher rocks are drab and bluish argillaceous to arenaceous shales and thin sandstones, which usually weather to an olive or yellowish-gray tint. At certain localities they are very fossiliferous, containing numerous specimens of *Spirifer granulosus*, *S. mucronatus*, *Athyris spiriferoides*, *Tropidoleptus carinatus*, *Chonetes coronata*, *Phacops rana* and other characteristic species of the Hamilton formation of New York, the fauna amounting to about 150 species. The formation, which varies in thickness from 1600 to 1650 feet, is named from the exposures near Romney, in northeastern West Virginia, and represents the Marcellus shale and Hamilton beds of New York, and No. VIII*b* and *c* of Pennsylvania.

In 1842 Emmons proposed the name Erie group for all the New York rocks between the base of the Marcellus shales and the top of the Chemung.[1] Mr. Darton, in 1892, proposed and defined the Romney shales, named from exposures in the vicinity of Romney, Hampshire county, in northeastern West Virginia,[2] which are now known to be equivalent to the Marcellus shales and Hamilton beds of New York. Messrs. Clarke and Schuchert, in 1899, used the term Erian in their revised classification of the New York series for the group composed of the Marcellus shales and Hamilton beds, and stated that it represented the "Erie Division" revived with a restricted meaning.[3]

It appears that the Romney formation is equivalent to the Erian group of New York; but the writer is undecided as to which name the laws of nomenclature entitle to recognition in Maryland.

Jennings formation.—The eastern area crosses the eastern part of the county from the northeast to the southwest; the second area lies to the west of Green Ridge, and in its northern half covers a large district to the north and east of the Romney formation; the third covers the lower part of Evitt's Creek valley between the two arms of the V-shaped Romney area, and

[1] Geology, New York, Pt. II, pp. 100, 429.

[2] Am. Geologist, Vol. X, pp. 17, 18. [3] Science, N. S., Vol. X, pp. 876, 877.

the fourth one is the broad band covering the lower part of the eastern face of Alleghany Front and extending from the Pennsylvania line southwesterly to the Potomac River above Keyser, W. Va. The lower part of the formation composed of thin, black, argillaceous shales in which a few species, such as *Buchiola speciosa*, *Lunulicardium fragile*, and *Styliolina fissurella* are common, immediately succeeds beds containing characteristic Hamilton fossils, and is well shown on Flintstone Creek, a few rods above its mouth, opposite the old Flintstone tannery; by the side of the National Road three miles northeast of Cumberland to the west of Evitt's Creek at Folks Mill, and on the Williams road east of Cumberland. This subformation corresponds in lithologic character and stratigraphic position to the Genesee shale of New York and No. VIII*e* of Pennsylvania.

Following this are olive to bluish fine argillaceous shales alternating with thin bedded sandstones. A few fossils occur in the more bluish layers. This division of the Jennings corresponds to the Portage formation of New York, or that facies named the Naples beds by Dr. Clarke, and No. VIII*f* of Pennsylvania. Dr. J. M. Clarke, who has described the Jennings fauna for the Maryland Geological Survey, writes me that the fauna of these two lower divisions of the Jennings formation "is very distinctly that of the Naples subprovince;" and he states that the lower division is considered "as an integral part of the Naples beds, bearing the Naples fauna."[1]

Succeeding the Portage are greenish arenaceous shales weathering to a buff color alternating with thin micaceous sandstones. Occasional layers are fossiliferous and the characteristic Chemung species, *Spirifer disjunctus*, is not uncommon. The lithological appearance of this part of the formation is quite similar to that of a considerable part of the Chemung in southwestern New York. Higher the sandstones predominate, and these vary in color from yellowish-gray through brownish-gray to dark red, and vary in texture from sandstone and grits to a white pebble conglomerate. Some of these sandstones are quite

[1] Letter of June 19, 1901.

massive, and in Jennings Run about one and one half miles above Corrigansville, a zone of grit and sandstone is thirty-five feet thick. The red rocks increase above this horizon, but Chemung fossils including *Spirifer disjunctus* extend some 650 feet higher, and the line between the Jennings and Hampshire

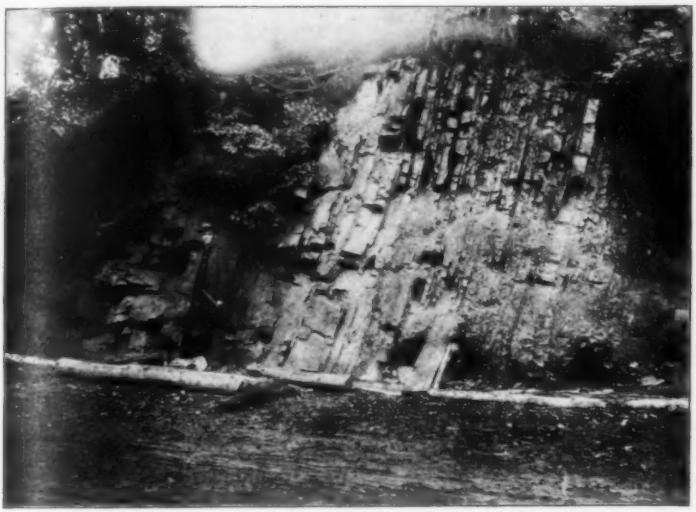

FIG. 2.—Heavy sandstone and conglomerate beds in the upper part of the Jennings formation, as shown by the roadside above Corriganville.

formations has been drawn at the top of this fauna. The formation is between 3800 and 4000 feet in thickness. The upper part of the Jennings may be correlated with the Chemung of New York or No. VIII*g* of Pennsylvania.

Hampshire formation.—This formation crosses the extreme eastern part of the county from the northeast to the southwest; the next area, which is the largest, flanks each side of Town Hill and crosses the county in the same general direction; while the third extends along the middle part of the eastern face of Alleghany Front. The rocks consist mainly of an alternation of red, flaggy, and massive sandstones and arenaceous or

argillaceous shales which both laterally and vertically merge gradually into each other and in the upper part of the formation shales, some of which are gray, and some brown in color, predominate. Some of the sandstones are crossbedded, and in the lower part of the formation, massive. The thickness varies from 1900 to 2000 feet. Fossils occur very infrequently. The formation is named from Hampshire county in northeastern West Virginia, a considerable area of which is underlain by it, and it represents at least part of the Catskill formation of New York, or No. IX of Pennsylvania.

CARBONIFEROUS STRATA

Pocono sandstone—The most eastern area of this formation, which forms the upper part of Town Hill, is mainly a massive conglomerate, while in the western area, extending across the county from Pennsylvania to West Virginia along the eastern face of Alleghany Front, the lower part of the formation is a coarse-grained, grayish-green, micaceous sandstone. Near the middle are shales containing fragments of plants, and the upper part is a grayish-green or reddish-green, micaceous, flaggy sandstone with some interbedded shales of various colors. Some of the layers are cross-bedded and others are conglomeratic. The thickness varies from 400 to 450 feet, and fragments of plants are the only fossils noted with the exception of a few shells apparently from this formation which were found nine miles northeast of Oakland, Garrett county. The formation is named from Pocono plateau in northeastern Pennsylvania, and is No. X of the Pennsylvania reports.

Greenbrier limestone.—This formation crosses the county as a narrow band along the eastern face of the Alleghany Front from Pennsylvania to West Virginia. The best exposures are in Jennings Run above the railroad water-tank; and on the north bank of the Potomac River below the mouth of Stony Run, as well as in the lower part of the run, two miles below Westernport. The lower part of the formation is composed largely of bluish-gray, arenaceous limestone, the middle of red and olive shales and the

upper part of massive bluish-gray limestones and calcareous shales. The limestone is valuable for road-metal and in Garrett county is quarried and burned to a considerable extent for quicklime which is used as a fertilizer. The thickness varies from 200 to 250 feet and the upper part is quite fossiliferous. The

FIG. 3.—Greenbrier limestone on western bank of Youghiogheny River, southwest of Oakland, Md.

formation is named from Greenbrier county in southeastern West Virginia where it reaches a thickness of 1000 feet or more.

Mauch Chunk formation.—This, like the preceding formation, crosses the county along the eastern face of Alleghany Front but the band is broader, covering the upper part of the mountain slope. The rocks are mainly red arenaceous and argillaceous shales and sandstones, but a little above the middle of the formation is about 100 feet of reddish thin-bedded standstones. At

the top of the formation, as shown in the Cumberland and Pennsylvania R. R. cut east of Barrelville, is a greenish zone five feet thick composed partly of sandstone and partly of a calcareous breccia containing clay pebbles. The thickness of the formation is 650 feet. In the lower part of the shales and along the Greenbrier–Mauch Chunk contact are numerous excellent springs. The formation is named from Mauch Chunk in eastern Pennsylvania and is the Canaan formation of the Piedmont folio. The Greenbrier limestone and Mauch Chunk shales taken together are known as No. XI of the Pennsylvania reports.

Pottsville formation.—The preceding three formations are usually grouped together as the sub-Carboniferous or Lower Carboniferous, and the Pottsville is classed as the oldest of the Carboniferous proper or Upper Carboniferous formations. It crosses the county from Pennsylvania to the Potomac, in general forming the crest line of Alleghany Front although in the northern part it is lower, and extends up the Potomac valley to above Westernport. At numerous places near the crest line of Alleghany Front it forms conspicuous cliffs. It also occurs at the northwestern corner of the county. The formation is composed of massive light gray sandstones with some conglomerate strata and thin-bedded gray sandstones and shales. Some of the shales are black and there are several thin beds of coal. The most important are first, the Bloomington, which is exposed along the Baltimore and Ohio Railroad west of Piedmont, W. Va., commonly known as the Railroad seam, varying in thickness from less than two to more than three feet and occurring about 150 feet below the top of the formation. The second is the Westernport seam about two feet thick which occurs below the Homewood sandstone near the top of the formation. Some of the sandstones are suitable for building stone. The thickness is estimated as between 450 and 500 feet and there are fragments of fossil plants. The formation is named from the exposures of massive conglomerate in the vicinity of Pottsville in eastern Pennsylvania. It is the Blackwater formation of the Piedmont folio and No. XII of the Pennsylvania reports.

Allegheny formation.—This is the first of the Coal-measure formations and in general covers the western slope of Alleghany Front extending from Pennsylvania to the Potomac valley and up it into Garrett county. It also extends up George's Creek valley from Westernport to the vicinity of Morrison's, one mile

FIG. 4.—Block of Pottsville conglomerate, at side of National Road on top of Meadow Mountain, Garrett Co.

below Barton; and occurs in the northwestern corner of the county. The rocks consist of massive to thin-bedded grayish to olive sandstones, gray and black shales and beds of fire-clay and coal. At Barrelville and on the northern part of Dan's Mountain two coal beds occur near the base of the formation which have not been found near Westernport. The lower one, called the "Bluebaugh" (Brookville) coal, varies in thickness from 2½ to 4½ feet and 30 feet or more above it is the "Parker"

(Clarion) coal with a thickness of two feet which was reported by the miners to reach 4½ feet. At Westernport nearly 100 feet above the base is an impure coal, called the "Split six-foot" by the miners, showing a thickness of 4 feet, and 130 feet above the base is the most valuable coal seam of this formation, the "Davis" (Lower Kittanning), commonly known as the "Six-foot," with a thickness of about 5 feet in the lower George's Creek valley. Nearly 170 feet above the Davis seam is the "Thomas" (Upper Freeport) coal, which forms the top of the formation, and from its general thickness in the George's Creek valley is known as the "Three-foot" seam. Fossil shells have been found in the black or bluish shales at a few localities. The thickness of the formation is about 300 feet. It is named from the exposures on the Allegheny River in western Pennsylvania, is very generally called the Lower Productive-measures, is No. XIII of the Pennsylvania survey and includes the Savage formation and lower part of the Bayard of the Piedmont folio.

Conemaugh formation.—The area south of the Pennsylvania line to a parallel line passing through Little Alleghany and to the west of the foot of the western slope of Little Alleghany and Piney mountains is largely covered by this formation. Then it extends parallel to Dan's Mountain, to the southwestern part of the county and covers a large portion of the steep slopes of the hills bordering the lower George's Creek valley, continuing up the valley to Ocean. It also appears in the upper part of a number of the small valleys along the western border of the county. The lower part of the formation, representing the Mahoning sandstone, is frequently a massive gray sandstone with bands of yellowish shales reaching a thickness of about 100 feet. In the upper part of this sandstone, about eighty-five feet above the Thomas coal, is a coal seam about two feet in thickness underlain by a stratum of fire clay. The succeeding rocks are grayish to brownish sandstones and yellowish to gray and black arenaceous and arigillaceous shales with beds of coal and fire clay. In some of the localities there are quite massive gray to brownish-gray sandstones near the middle and top of the

formation. From 225 to 230 feet above the Thomas coal and base of the formation and about 400 feet below the Elkgarden coal is a coal seam with a general thickness of four feet, but varying from three to nearly five feet, named the Barton (Four-foot) coal, and worked to a considerable extent in the vicinity of that town. A thin seam nearly one foot thick in outcrop occurs about 440 feet above the Thomas coal or 220 feet below the Elkgarden, while approximately 500 feet above the Thomas coal and 150 feet below the Elkgarden coal is a zone composed of alternating shales and impure coal, varying in thickness from seven to ten feet, known locally as the "Dirty Nine-foot" and called the "Franklin" coal. In the Lonaconing section, thirteen feet below the base of the Franklin coal are nearly three feet of coal and black, thin shale. There are also two or three impure limestone strata and some irregular beds of iron ore. The formation is clearly defined by the top of the Thomas coal at the base and the base of the Elkgarden (Pittsburg) coal at the top, the thickness varying from 600 to nearly 640 feet. A few invertebrate fossils have been found, principally on the bank of George's Creek at Barton, and fossil plants in the black shales.

The Conemaugh formation was named from the Conemaugh River in western Pennsylvania, is frequently called the Lower Barren-measures, is No. XIV of the Pennsylvania reports, is the upper part of the Bayard and Fairfax formation of the Piedmont folio, and the Elk River series of West Virginia.

Monongahela formation.—This formation, south of an east and west line passing through Little Alleghany, covers the larger part of George's Creek valley as far south as Ocean and most of the area west to the county line. To the north of Little Alleghany, two high hills are capped by it. From Ocean to Lonaconing the upper part of the steep hills bounding the George's Creek valley are in the Monongahela, which also caps most of the highest hills as far south as Hampshire to the northeast of Westernport. The rocks consist largely of light gray to black shales with some grayish sandstones which form occasional massive strata. There are also several dark colored limestones,

bands of iron ore, and beds of coal. The Elkgarden (Pittsburg) coal, the noted seam of western Maryland, and known locally as the "Big Vein" or "Fourteen-foot" seam, occurs at the base of this formation. The main mass of coal varies in thickness from ten to nearly fourteen feet, above which are frequently from three to nine feet of alternating coal and black shale which, in the southern part of the George's Creek field, is capped by twenty-five feet of thin black shales in which coal occasionally occurs.

A seam of coal two and one half feet in thickness is reported in the Consolidation Coal Company's new shaft 92 feet above the base of the Elkgarden coal. From 120 to 140 feet above the top of the Elkgarden is the Tyson (Sewickley) coal varying in thickness from three to seven feet. Finally, at the top of the formation about 255 feet above the base of the Elkgarden coal is the Koontz (Waynesburg) coal two feet thick and reported to reach a thickness of four and one half feet. The top of this coal determines the upper limit of the Monongahela formation which has a thickness of a little more than 250 feet. Fossils are rare.

The Monongahela formation was named from the exposures along the Monongahela River in southwestern Pennsylvania, is popularly known as the Upper Productive-measures, is No. XV of the Pennsylvania reports and the Elkgarden formation of the Piedmont folio.

PERMIAN STRATA (?)

Dunkard formation.—The largest area of this formation partly underlies the city of Frostburg and covers a considerable tract to the east and southeast of the city. It covers the high part of several hills to the south of Frostburg, extending as far south as Detmold Hill on the western side of George's Creek and the hill south of Pekin on the eastern side. The rocks consist largely of argillaceous shales, which when weathered are reddish-green, with some beds of sandstone, limestone, and coal. A stratum of coal and black shale four feet thick occurs 120 feet above the base of the formation and a drab limestone, five feet

thick, weathering buff occurs about 295 feet above it. This limestone, some of the layers of which contain plenty of specimens of Ostracods (*Primatia frostburgensis* Jones) and a few other species, has been quarried to some extent toward the top of Vale's Hill, east of the Consolidation Coal Company's pumping station, and it is succeeded by thin black shales. The top of the hill is ninety feet higher and on its slope forty feet above the limestone ledge are loose pieces of bluish thin-bedded limestone containing small Ostracod and Gastropod shells. Near the top are loose blocks of coarse-grained sandstone which probably caps the hill. This hill shows about 390 feet of the Dunkard formation, which is probably its greatest thickness in the county. In addition to the fossils noted in the limestones, ferns were found in the shales overlying the Koontz coal.

The formation is named from the exposures along Dunkard Creek, near the West Virginia-Pennsylvania line, is frequently called the Upper Barren-measures, and is No. XVI of the Pennsylvania report.

CHARLES S. PROSSER.

COLUMBUS, O.,
July 1901.

THE DEPOSITION OF COPPER BY SOLUTIONS OF FERROUS SALTS

INTRODUCTORY

THE genesis of the great deposits of native copper is a subject which has invited considerable speculation. From its occurrence in the cupriferous conglomerates and sandstones as a cement, or replacer, of the constituent grains, the copper is plainly of secondary origin. Its position here indicates that it resulted as a deposition from aqueous solution.[1] The metal, doubtless, first dissolved as sulphate, an oxidation-product of an original sulphide. Under the influence of solutions of calcium bicarbonate, or alkaline silicates, the sulphate was speedily converted into the carbonate, or silicate.[2] From solutions of one, or both, of these latter salts were probably derived the several classes of copper deposits.

In its paragenetic relations the position of the metallic copper indicates, as Pumpelly shows, that it was deposited after the formation of the non-alkaline silicates and before that of the alkaline silicates. As is further pointed out by the same writer, there is an intimate connection between the native copper and such iron-bearing minerals as delessite, epidote, and the green earth silicates. So constant is their common occurrence that he is led irresistibly to the conclusion that there is a close genetic relation between the reduced copper and the ferric oxide contained in the associated minerals; that, indeed, the reduction of the copper oxide to metallic copper was produced by the oxidation of ferrous derivatives. Later Irving, in support of the same view, called attention to the fact that many particles of copper enclosed a central core of magnetite.[3]

[1] R. D. IRVING: Mon. U. S. Geol. Surv., No. 5 (1883), p. 420.

[2] RAPHAEL PUMPELLY: Am. Jour. Sci., Vol. II (1871), p. 353.

[3] Mon. U. S. Geol. Surv., loc. cit.

A number of attempts has been made to discover the conditions under which copper may be deposited by solutions of ferrous salts. As early as 1861, Knop succeeded in forming cuprous hydroxide by treating a mixture of cupric and ferrous sulphates with alkaline carbonate.[1] In one instance he speaks of obtaining traces of copper. In 1864, Wibel repeated Knop's experiments,[2] but was unable to verify the latter's statement regarding the reduction to metallic copper. When, however, a mixture of ferrous and cupric hydroxides, formed by adding potassium hydroxide to a solution of the sulphates, was heated to 210° C., traces of copper were obtained. Solutions of the sulphates and coarsely powdered Wollastonite, subjected to the same treatment, yielded a like result. The separation of metal, however, was slight and the part played by the ferrous hydroxide in the reduction was at the time somewhat questioned. In 1867, Braun observed the partial deposition of copper from a mixture of ferrous and cupric salts when these were dissolved in large excess of ammonium carbonate.[3] The same year Weith secured a ready reduction in the presence of tartaric acid.[4] He failed to note, however, that under the same conditions, the organic acid itself will slowly reduce the copper salt. A mixture of calcium hydroxide with a solution of ferrous and cupric sulphates, was allowed to stand for several weeks. The precipitate thus obtained, when treated with acetic acid, left a residue of cuprous oxide and copper.

Strangely enough Weith overlooked the fact that cuprous oxide with acetic acid yields cupric acetate and metallic copper. In 1869, Hunt[5] stated that he had obtained metallic copper by the action of cupric chloride on freshly precipitated ferrous hydroxide, or carbonate. Nothing is given, however, to indicate that the metal was actually detected by isolating it from co-precipitated ferric hydroxide.

[1] A. KNOP: N. Jahrb. f. Min. (1861), S. 513.

[2] FERD. WIBEL: "Das Gediegen-Kupfer und das Rothkupfererz" (1864), S. 14.

[3] E. BRAUN: Zeit. für Chem. (1867), 569.

[4] W. WEITH: Zeit. für Chem. (1867), 623.

[5] STERRY HUNT: Comp. r. (1869), 1357.

THEORETICAL

It can be shown that the deposition of copper by solutions of ferrous salts is a reversible reaction governed by the ordinary laws of chemical equilibrium. It is to Arrhenius largely that we owe the view that certain substances in solution are more, or less, dissociated into electrically charged parts, or ions. This theory has proved of the highest value in affording an insight into the principles of chemical reactions. Different substances differ much in their tendency to pass into the ionic form and this tendency is greatly influenced by external conditions, particularly by the nature of the solvent.

The chief source of ions is the dissociation of electrically neutral molecules, such as occurs in the aqueous solutions of salts, acids, and bases. They may further be formed from electrically neutral substances which enter the ionic condition by partially, or wholly, appropriating the electric charge of ions already present.[1] As an example of this mode of formation may be mentioned the reduction of ferric salts by the action of metallic iron. $2FeCl_3 + Fe = 3FeCl_2$. The solution of metallic copper in ferric chloride is an action of the same nature. $Cu + 2FeCl_3 = CuCl_2 + 2FeCl_2$.

As is seen the deposition of copper by a ferrous salt would be the reverse of this last reaction.

The conditions under which such reduction should occur may be readily determined. In a system which contains a solution of iron and cupric salts in contact with metallic copper and in which the several constituents have attained a constant value, a condition of equilibrium subsists on the one hand between ferric, cuprous, ferrous, and cupric ions ($Fe''' + Cu' \rightleftarrows Fe'' + Cu''$), and on the other hand between ferric, ferrous, and cuprous ions and the active mass of the metallic copper ($Cu + Fe''' \rightleftarrows Fe'' + Cu'$). If a, b, c, d, respectively, represent the active masses of the ions in the first instance, an equation of equilibrium may be thus formulated, $\frac{ab}{cd} = K$.[2] The active mass of the copper

[1] F. W. KÜSTER: Zeit. f. Elec. Chem., Vol. IV, p. 105.

[2] W. NERNST: Theoretical Chemistry, p. 358.

is of constant value, hence in the second instance, retaining the same letters, we have the expression, $\frac{a}{bc} = K'$. The precipitation of copper would then be favored by increasing the concentration of ferrous, cuprous, and cupric ions and by decreasing that of the ferric ions. The deposition of the metal, consequently, should depend on the relative active masses of the ions present. This assumption is fully sustained by the experimental evidence which follows:

The precipitation of metallic copper by solutions of ferrous salts is a reversible action, whose direction in any case is determined by the relative concentration of the ferrous, ferric, and copper (cuprous and cupric) ions.

EXPERIMENTAL [1]

(*a*) In a solution containing an appreciable quantity of ferric ions, or in which these would be formed in the course of the reaction, metallic copper will not be deposited.

This is shown in the inability of ferrous chloride, or sulphate, to reduce corresponding copper salts, even though the mixed solutions stand for an indefinite period. This inaction is, indeed, to be expected when we consider that solutions of soluble ferric salts, as the sulphate and chloride, easily dissolve metallic copper with formation of a cupric salt.

From this it is readily understood why Wibel [2] obtained no reduction of the copper salt on heating together to 210° C. a solution of the mixed sulphates.

(*b*) In a solution containing few ferric ions and in which the reaction does not result in their appreciable increase, a sufficient concentration of ferrous and copper ions will result in the deposition of metallic copper.

The tendency of ferrous to reduce copper salts is shown in the precipitation of cuprous sulphocyanate by the action of the ammonium salt on a solution of ferrous and cupric chlorides. The same tendency appears in the formation of cuprous chloride,

[1] All the reactions given in the following paragraph have been experimentally determined by its author except as indicated by references.—Ed. JOUR. GEOL.

[2] "Das Gediegen-Kupfer und das Rothkupfrerz," S. 20.

as noted by Hunt, on heating cupric oxide with a solution of ferrous chloride.[1] From an emulsion of ferrous and cupric hydroxides, after long standing, may be separated crystals of cuprous oxide. That further reduction is largely determined by the concentration of the cupric and ferrous ions, appears probable from the action of ammonium carbonate on a solution of ferrous and cupric chlorides.[2] The precipitate first formed on adding the carbonate to the mixed chlorides, dissolves in an excess of the precipitant to a yellow liquid, from which, on standing twenty-four hours, there is deposited, on the walls of the vessel, a slight but brilliant mirror of metallic copper.

The influence of the concentration of the ions on the reduction of copper is clearly shown in the behavior of the mixed carbonates under varying conditions.

When one adds a solution of cupric and ferrous chlorides (1 mol. $CuCl_2$: 2 mol. $FeCl_2$) to a considerable excess of sodium carbonate, there is obtained a greenish precipitate of the carbonates which undergoes but slight change on standing. Such a solution, indeed, would naturally little favor the separation of metallic copper since the highly ionized alkaline carbonate would greatly decrease the active masses of the ferrous and cupric ions.

If the alkaline carbonate employed be only slightly in excess of that required to precipitate the copper and iron salts, the concentration of the carbonic acid ions will be greatly diminished. Under these more favorable conditions reduction slowly takes place with loss of carbon dioxide. The carbonates gradually change in color to a brick-red precipitate containing metallic copper and basic ferric carbonate.

As is well known the acid ferrous and cupric carbonates are more soluble than the corresponding normal or basic salts of these metals. The influence of this greater solubility is shown in the precipitation of small amounts of copper even in the presence of large excess of acid alkaline carbonates. If one adds

[1] STERRY HUNT : Comp. r., loc. cit.

[2] E. BRAUN : Zeit. für Chem., loc. cit.

the metallic chlorides to a saturated solution of acid potassium carbonate and allows the mixture to stand for twenty-four hours there is deposited on the walls of the vessel a slight film of metallic copper mixed with basic ferric carbonate.

The solubility of the acid carbonates of iron and copper is largely increased under pressure.[1] The greater concentration of the metallic ions thus obtained produces a ready reduction of copper even in the presence of concentrated solutions of the acid alkaline carbonates.

In a thick-walled flask holding a saturated solution of potassium bicarbonate is placed a tube containing a solution of ferrous and cupric chlorides. The flask is then filled with carbon dioxide, tightly sealed, and the contents of the tube mixed with the alkaline bicarbonate. The precipitate formed gradually loses carbonic acid, finally assuming the brick-red color already noted. The supernatant ruddy liquid owes its color to the presence of some basic ferric carbonate which, when the solution is warmed, deposits as ferric hydroxide. The precipitate contains finely divided copper which cannot readily be freed from the intimately associated ferric iron by treatment with hydrochloric acid because of the solvent action of ferric chloride, but on digesting the original mixture a short time a coagulum may usually be formed from which, by repeated agitation with water, the heavier metal is separated. The copper thus obtained is of characteristic appearance; is insoluble in hydrochloric acid, soluble in nitric, the solution showing the presence of copper and absence of iron.

The reduction of copper from the cuprous condition may be effected in the same manner as from the cupric. This is readily shown by substituting for the cupric salt in the above reaction cuprous chloride dissolved in a solution of chloride of sodium. From one gram of cuprous chloride more than half the metal may be easily isolated as pure copper free from ferric iron.

From these results it is quite evident that the conditions

[1] R. WAGNER: Zeit. f. analyt. Chem. Vol. VI, p. 167.

under which the oxidation of ferrous salts may result in the deposition of copper are those which obtain in the circulation of underground waters. The theory of Pumpelly and others based on paragenetic relations is thus fully sustained by chemical evidence.

H. C. BIDDLE.

UNIVERSITY OF CHICAGO,
June 1901.

EVIDENCE OF A LOCAL SUBSIDENCE IN THE INTERIOR

In the spring of 1883, I made a survey to build a levee along the Wabash River on the west side of Parke county, Indiana, for a length of twelve miles. I took the levels with great care, and checked on the river water every half mile to guard against errors. The great flood of the preceding winter had left its high water mark very plain on the trees in the bottoms, and I checked on them also. I cut some sixty bench marks on the trees in running the levels, some of which are still intact. The lower end of the levee was built square across the narrow bottom to the bluff and crossed a bayou through which the flood water ran off of the bottoms into the river. We built an automatic flood-gate across this bayou so as to shut out river, but let out inside water from breaks above. The gates were hung to heavy brick walls built on timber foundations three feet thick, and deeply bedded below the bottom of the bayou. A bench mark was cut on a bur oak tree near the walls, and the level of the walls was taken when built. I had charge of the maintenance and repair of this levee four years from its building, and had frequent occasion to run the level over the top to restore breaks, for it was built only twenty-one feet above low water, whereas the great floods rise twenty-eight feet. I set the grade stakes for the contractors to work to, and in doing so ran the level over the ground again. I speak of all this to show that my leveling was correct, as so many levelings would detect any error, and none were found to exceed a half inch. I can say positively that the levels were correct in 1883.

This spring (1901) the levee was to be raised three feet, making it twenty-four feet above low water, under a new law of the state, but including only the lower seven miles. I leveled the work again, and found bench marks again intact except the

lower (south) mile and a quarter, which showed a decline southward amounting to ten inches at the lower (south) end, as shown by the mark on the bur oak and top of the gate walls. I went back to the C. & E. I. railroad bridge at Clinton, two and a half miles above the south end, and started my level from a mark known to be in tally with the level of 1883, and ran carefully over the work again, and it varied from the one made just before only a quarter of an inch. And the bench mark on the bur oak and the top of the gate walls had gone down ten inches ($\frac{83}{100}$ of a foot). I was right in 1883 and I am right now. What caused this sink, or subsidence? I can think of nothing so likely to cause it as the Charleston earthquake. The wave of that earthquake somewhere south of us changed from westward and went northward along the Wabash.

JOHN T. CAMPBELL.

ROCKVILLE, INDIANA,
July 20, 1901.

EDITORIAL

WITH the death of Dr. Joseph Le Conte there has passed away perhaps the last distinguished American representative of the general geologist as typified during the past century. This passing type of the general geologist was a distinctive outgrowth and representative of a transitional stage of intellectual procedure—a passage from the former mode in which the generalizing and philosophical factors held precedence and the toilsome modes of scientific verification followed as their servitors, to the present or at least the coming method in which scientific determinations are the basal factors to which generalizations and philosophies are but dependent accessories. We owe much of the transition itself to Dana and Le Conte, the two noblest American representatives of the passing type, for while they grew up under the influence of the older intellectual attitude, they grew out of it in spirit while they steadied and guided the transition. They were distinctively students of geology in the special sense in which that term implies the organized *doctrine* of the earth, rather than students of what might be termed *geics*, the immediate study of the earth itself in the field and the laboratory. They were preëminently students of the accumulated data and of the literature of the science, with generalization and philosophic inference as their dominant inspiration. Neither Dana nor Le Conte were eminently field students; much less were they specialists in a chosen field of the broad geological domain. Their point of view was that of the organizer and of the philosopher, and the contribution they made in their chosen sphere was indispensable and immeasurably valuable. How this necessary function is to be met in the future, with the increasing complexities and profundities into which every branch is rapidly growing, it is difficult to foresee, further than that it must in some way be intimately associated with extensive personal researches in the field and the laboratory, and must be guided

by a reversal of the old-time attitude of philosophy and science toward each other. The philosophical factor must be put into service as the active handmaid of scientific determination rather than as its guide and leader. It may indeed go before as scout to roughly reconnoiter the way, and it may come after to assemble and interpret the results, but it must ever be tentative and dependent on rigorous scientific determination. Deduction, inference, interpretation, theory, hypothesis, and the other philosophical factors must be merely initial steps and sequential steps attendant on rigorous science as the end. None the less, the philosophical factors and the philosophical point of view are indispensable if the science is to make its most wholesome progress, and we owe to Le Conte and to those he typifies an immeasurable debt, for they have kept us in fresh touch with the generalizations and the philosophy of the science, and have inspired us with their own contributions to the broader conceptions of geology and of its relations to kindred sciences. The writings of Le Conte are graced by the fruits of wide learning, a lucid style, a genial attitude, and a candor that has called forth universal love and admiration. T. C. C.

THE progress of opinion in regard to the origin of the solar system, and incidentally of the earth, is indicated by the following recent utterances of astronomers of high rank:

This simple hypothesis (Laplace's nebular hypothesis) has recently been severely attacked, and it is doubtful whether it will survive the blow. Indeed, we may be compelled to seek the origin of stellar systems in the spiral nebulae, which Keeler's photographic survey made just before his death showed to represent a true type form. It is evident that much remains to be done before the mystery which surrounds the genesis of stars can be cleared away.— PROFESSOR GEORGE E. HALE, Director Yerkes Observatory, in address to Visiting Committee, *University Record*, June 28, 1901, p. 141.

Though, without doubt, the system was evolved in some way from a primitive nebula, we may say with certainty that it did not follow the orderly course marked out for it by Laplace.— PROFESSOR C. L. DOOLITTLE, of the University of Pennsylvania, in annual address delivered before the University of Pennsylvania chapters of the Society of Sigma Xi, June 13, 1901, printed in *Science*, July 5, 1901, pp. 11–12.

Reviews

SUMMARIES OF CURRENT NORTH AMERICAN PRE-CAMBRIAN LITERATURE.[1]

WALCOTT[2] reports on the results of an examination of Cambrian and pre-Cambrian formations on Smith's Sound, Newfoundland, during the summer of 1899. At Smith point he found the Olenellus fauna 369 feet below the summit of the Etcheminian, and one of its types, Coleoloides typicalis, in the basal bed of the Cambrian, on the south side of Random Island. This retains the Etcheminian of Newfoundland in the Lower Cambrian.

The Random terrane, so-called from a typical section on Random Sound, is a series of sandstones, quartzitic sandstones, and sandy shales, resting conformably upon the Signal Hill conglomerate (which was formerly supposed to represent the top of the Avalon or Algonkian series) and extending up to the base of the Cambrian. The Random terrane is thus the upper member of the Avalon series and fills a portion, if not all, of the gap between the Signal Hill conglomerate and the Cambrian. The Cambrian rests on the Random terrane with a thin belt of conglomerate. The thickness of the terrane is probably 1000 feet. In one horizon in the terrane were found several varieties of annelid trails, including a variety about 5 millimeters broad, a slender form ½ millimeter broad, and an annulated trail 2 to 3 millimeters in width.

An examination of the form known as Aspidella terranovica found in the Momable terrane of the Avalon series proved the supposed fossil to be a spherulitic concretion, and this removes it from among the possible pre-Cambrian forms of life.

Cushing[3] describes and maps the pre-Cambrian rocks of Franklin

[1] Continued from p. 87, Vol. IX, this JOURNAL.

[2] Random, A Pre-Cambrian Upper Algonkian Terrane, by CHARLES D. WALCOTT: Bulletin of the Geological Society of America, Vol. XI, 1900, pp. 3–5.

[3] Preliminary Report on the geology of Franklin county, Pt. III, by H. P. CUSHING: Eighteenth Annual Report of the State Geologist of the State of New York, 1900, pp. 75–128. With geological map.

county, New York. These are classified as Grenville (Algonkian) rocks, igneous rocks intrusive in the Grenville, and other igneous rocks of doubtful age, possibly in part older than the Grenville rocks.

The Grenville rocks occur in small disconnected patches surrounded by intrusive igneous rocks. Some of them have such position with reference to one another that they seem to represent remnants of what were originally two continuous parallel N. E. to S. W. belts. The characteristic rock of the series is the crystalline marble. This is intricately infolded with quartzose and hornblendic gneisses, and with fine-grained granitic, syenitic, and gabbroic gneisses precisely like gneisses which occur in other areas where no member of the Grenville series is to be found.

The gneisses of undetermined age include granite, syenite, diorite, and gabbro gneisses, together with intermediate varieties. They occupy a very large area. If all these gneisses are igneous (as is thought probable) there are three possibilities in regard to their age.

1. They may represent in whole or part a more ancient series than the Grenville.

2. They may represent a somewhat later series intrusive in the Grenville, but older than the great gabbro, syenite, and granite intrusions.

3. They may represent thoroughly foliated phases of these later intrusions.

In Dr. Cushing's present judgment they will be found to belong partly under 2 and partly under 3, but more especially the former.

No rocks have been found in the northern Adirondacks which can be shown to be older than the Grenville series, but in every case in which the relations have been made out, the adjacent rocks show intrusive contacts with the Grenville rocks. On the other hand, the Grenville is a sedimentary series and must have been laid down on some floor.

Younger than the Grenville rocks and for the most part younger than the doubtful gneisses are a considerable quantity of igneous rocks comprising gabbros (anorthosites) syenites, and granites. These again occupy large areas.

In the northern portion of the county, Upper Cambrian rocks overlie the pre-Cambrian rocks with unconformity.

Smyth [1] discusses certain features of recent work in the western

[1] The Crystalline Rocks of Western Adirondack Region, by C. H. SMYTH: Rept. of the New York State Geologist for 1897, published in Fifty-first Ann. Rept. of New York State Museum, Vol. II, 1899, pp. 469–467.

Adirondack region. He concludes that the rock previously called gabbro by Nason, Van Hise, Williams, and himself, south of the belt of limestone in the Diana-Pitcairn area in Lewis and St. Lawrence counties, is an augite syenite of igneous origin, although it passes into a hornblende-gneiss which is unquestionably a result of dynamic action. The origin of other gneisses has been inferred to be igneous from their similarity to this gneiss which has been particularly studied, and it is evidence of this kind which serves as a basis for Smyth's conclusions, previously published,[1] that some of the gneisses on the western Adirondacks are certainly, and most of them probably, of igneous origin.

With the view of exploring the central and little known portion of the Adirondacks, a reconnaissance was made through the area contiguous to the Fulton chain of lakes and Raquette Lake in the counties of Hamilton and Herkimer. It was found that the heart of the Adirondacks is made up essentially of gneiss, with minor quantities of crystalline limestone and its associated sedimentary gneisses and schists. This is precisely analogous to what was found by the writer in St. Lawrence, Jefferson, Northern Lewis, and southwestern Hamilton counties, and by Kemp and Cushing in the eastern Adirondacks. These facts lead to the conclusion that the Adirondack region, instead of consisting of a great central mass of gabbro, surrounded by a narrow fringe of gneisses and limestones with quaquaversal dip, is essentially composed of gneisses, with numerous limestone belts, having northeast strike, and northward dip, and cut through on the east by immense intrusions of gabbro. It is still possible, of course, that some areas of gabbro may be found in the unexplored portions of the western half, but even should this be so, it would not materially modify the above conclusion, as such masses must necessarily be isolated intrusions of no great extent, rather than parts of a large area.

Kemp,[2] in connection with the description of the magnetite deposits of the Adirondacks, briefly describes the general features of the geology of the gabbro and gneiss of Westport, Elizabethtown, and Newcomb townships in Essex county, New York, and presents a geological map of the former two townships.

[1] See Summary JOUR. GEOL., Vol. VII, p. 406.

[2] The Titaniferous Iron Ores of the Adirondacks, by J. F. KEMP: Nineteenth Ann. Rept. U. S. Geol. Surv., 1897–8, Pt. III, 1899, pp. 397–399.

Kemp and Newland[1] make a preliminary report on the geology of Washington, Warren, and parts of Essex and Hamilton counties, New York. Some of the points particularly noted are:

The excessive mashing and granulation of the gneisses, giving them in places semblance to quartzite. The greenish gneisses, consisting in largest part of microperthite, were originally eruptive rocks. The discovery is reported of quartzose gneisses or foliated quartzites which are certainly metamorphosed sediments. They form notable areas along the head of South Bay, Whitehall township. Their presence indicates the probable presence of a considerable series of clastic sediments. The crystalline limestones themselves have been found in small exposures over almost all of Warren county, and generally in the crystalline belt of Washington. They are most extensive in Newcomb and Minerva townships of Essex, and to the south become thinner and more scattered. So far as we have observed they are less common in eastern Hamilton county. There is evidence to show that stratigraphical relations can be proven and that anticlines and synclines can be demonstrated.

Dikes of basic gabbro usually of moderate width, but lithologically like the larger masses in Essex county, have been met over a wide area — in fact almost every township in Warren, but the basaltic traps almost disappear.

Kemp[2] summarizes the present knowledge of the pre-Cambrian rocks of the Adirondacks. Most of the features have been covered in previous articles. Attention is called to the distribution of the sedimentary crystalline rocks, the Oswegatchie series (equivalent to the Grenville series of Adams and perhaps the Huronian). These consist of limestones, sedimentary gneisses, and quartzites. They occupy greater area than has been supposed. The limestones are found chiefly in the northwest, and the southeast or eastern portions of the Adirondack area of crystalline rocks. They are in small quantity, or altogether absent in the northern portion, in the broad belt running from

[1] Preliminary Rept. on the Geology of Washington, Warren, parts of Essex and Hamilton counties, by J. F. KEMP and D. H. NEWLAND: Rept. of the New York State Geologist for 1897, published in Fifty-first Ann. Rept., New York State Museum, Vol. II, 1899, pp. 499–553.

[2] Pre-Cambrian Sediments in the Adirondacks, by J. F. KEMP: Vice Presidential address published in the Proceedings of the A. A. A. S., Vol. XLIX, 1900, pp. 157–184.

northeast to southwest across the area, and along the southern and southwestern border. On the northwest they are in extended and comparatively broad belts, but in the eastern portion they appear in many small and separated exposures, associated with some quartzites and much greater amounts of characteristic gniesses, but greatly broken up by igneous intrusions. The quartzites thus far known are in small quantity, but such as they are, they are found principally in the eastern portions of the area, where the limestones are thinnest and most scattered. From the presence of the quartzites it is inferred that clastic sediments must have been present in larger amounts than has heretofore been realized. On the east it has not been proven that sediments form synclines pinched into the underlying gneissoid rocks. On the contrary they seem to constitute low, dipping, flat monoclines.

Comment.—The complex geology of the Adirondack crystalline rocks is being rapidly worked out by Kemp, Smyth, Cushing, and others. The frequent brief papers issued by these geologists in nearly all cases report some important advance in the solution of their problem. The precise relations of these advances to the general problem may not be clear to the average geological reader, too busily engaged to follow the subject closely, and for such the general summary of Adirondack geology given by Kemp[1] will be of value.

In a previous comment[2] on Adirondack geology the state of geological knowledge, as indicated by the literature on the subject then available, was briefly summarized by the writer, and here attention will be called only to later developments. One of the most interesting of these is the extension of the areas of pre-Cambrian sedimentary and associated rocks, and the corresponding contraction in the area of the great Adirondack gabbro. This was formerly supposed to occupy the great central area of the Adirondacks with the pre-Cambrian sediments and the associated gneisses around its periphery. Recent work seems to show that the area is occupied by gneisses, with narrow limestone belts, cut through on the east by a number of immense intrusions of gabbro. Another advance is the discovery of greater quantities of clastic sediment than have before

[1] Pre-Cambrian Sediments in the Adirondacks, by J. F. KEMP: Vice Presidential address published in Proceedings of the A. A. A. S., Vol. XLIX, 1900, pp. 157–184.

[2] JOUR. GEOL., Vol. VII, pp. 410–411.

been realized in the eastern portion of the Adirondack area, where the limestone is thinnest. The main problem of the region, the origin of the gneisses, is as yet far from settlement. The tendency is, however, to ascribe to them an igneous origin, and to place them later than the Oswegatchie series, in the areas where they have been most closely studied.

Jones,[1] in connection with a description of Tallulah Gorge of northeastern Georgia, describes the crystalline rocks there occurring, and gives a little sketch map showing their relations. They are called pre-Cambrian.

Watson[2] describes the granitic rocks of the Piedmont plateau of Georgia. Field and laboratory studies indicate that they are not all contemporaneous in origin. Some of them are pre-Cambrian, while others may possibly be later in age.

Adams[3] describes the Laurentian granitoid gneiss and granite of the Admiralty group of the Thousand Islands, Ontario. The granitoid gneiss is presumably derived by metamorphism from the granite. A large exposure of crystalline limestone on Island No. 18 resembles in all respects that of the Grenville series of the mainland adjacent.

Parks[4] describes the geology of the Moose River Basin in Canada, including the Moose and Abitibi Rivers, tributary to James Bay. This is an immense triangular area of which the apex is at James Bay, and the base stretches from above Lake Abitibi to a point west of Kabinakagami. The southern and major portion of this triangular area consists of Laurentian gneisses and granites crossed, by bands of Huronian rocks. Along the Abitibi River, Huronian rocks, consisting of altered diorites, pyrites, gray quartz schists, and some soft decomposed schists occupy the country to the south, extending as far north as the head of the first long rapid on the Frederick House River. The line of contact of this belt crosses the Abitibi below the Iroquois

[1] The Geology of the Tallulah Gorge, by S. P. JONES: American Geologist, Vol. XXVII, 1901, pp. 67–75.

[2] The Granitic Rocks of Georgia and Their Relationships, by T. L. WATSON: American Geologist, Vol. XXVII, 1901, pp. 223–225.

[3] Notes on the Geology of the Admiralty Group of the Thousand Islands, by FRANK D. ADAMS: Can. Rec. of Sci., Vol. VII, 1897, pp. 267–272.

[4] PARKS, WILLIAM A.: The Nipissing-Algoma boundary, Eighth Rept. Ont. Bur. Mines, 1899, pp. 175–204, with geological map; Niven's base line, Ninth Rept. Ont. Bur. Mines, 1900, pp. 125–142; The Huronian of the Moose River Basin, University of Toronto Studies, Geol. Series No. 1, 1900, pp. 35, with sketch map.

Falls. From this point to the Lobstick portage, Laurentian gneisses and mica schists crop out occasionally. The narrow Huronian belt from the Lobstick to the foot of the canyon or Long Portage, consists mainly of augite-syenite, passing into gabbro to the north. Beyond this portage Laurentian gneiss extends to the Devonian contact above the Sextant rapids.

Coleman[1] gives a general account of a visit to all the iron and copper regions of the Lake Superior country. For the ranges on the United States side of the boundary no facts are given not found in the published reports. On the Canadian side of the boundary the Michipicoten Range, the iron formation near Dog River, and the siliceous iron ores of Batchawana Bay are described. In the Michipicoten range the Helen mine in particular is referred to. In general, the rocks, including the ore at this mine, have all the appearance of Lower Huronian or Keewatin rocks, as in the Vermilion district, and not those of the Upper Huronian or Animikie, as in the Mesaba.

Near Dog River are iron formation rocks similar to those extending northeast from Michipicoten bay. It is thought probable that the two may connect.

The occurrence and relations of iron formation material northeast from Michipicoten Bay and near Dog River are indicated on a sketch map.

Coleman,[2] as a result of an examination of the new Michipicoten iron district, and the consideration of other iron formation areas in Ontario, has collected facts which seem to throw some light on the relative ages of the different areas mapped as Huronian on the north shore. In the Michipicoten district iron-formation material, consisting of banded ferruginous sandstones, cherts, and jaspers, standing nearly vertical, extends from Little Gros Cap northeastward for twenty miles; then bending to the north and west it takes a westerly direction for more than thirty miles. The width of the belt is but a few hundred yards.

Sandstones of the same peculiar type occur at Little Turtle Lake, east of Rainy Lake and near Fort Frances, on Rainy River, as well as at the Scramble gold mine, near Rat Portage, on Lake of the Woods.

[1] COLEMAN, DR. A. P.: Copper and Iron Regions of Ontario, by A. P. COLEMAN. Report of the Ontario Bureau of Mines for 1900, pp. 143–191.

[2] Upper and Lower Huronian in Ontario, by ARTHUR P. COLEMAN: Bull. Geol. Soc. Am., Vol. II, 1900, pp. 107–114.

Thin sections of these rocks show the same polygonal shapes of the grains of quartz, and more or less iron ore is associated with specimens from each locality. It is very probable, then, that the same horizon exists at points far to the west of Lake Superior.

Turning toward the east, specimens very like the jaspery varieties of the Michipicoten iron range are found interbedded with iron ores near Lakes Wahnapitae and Temagami, between Sudbury and the Ottawa River.

At Batchawana Bay at the southeast end of Lake Superior, a siliceous rock with narrow bands of magnetite occurs, which is probably the equivalent of the Michipicoten rock.

If, as seems probable, these jaspers are the equivalents of the western Huronian sandstones, there is a definite horizon traceable from point to point across the whole northern end of the province, a distance of more than six hundred miles.

At a number of places over this area conglomerates, containing jasper, ferruginous sandstone or chert pebbles, probably derived from the source above described, are known. Beginning at the west, some of these conglomerates occur as follows: on Shoal Lake, east of Rainy Lake; west end of Schist Lake; near Mosher Bay, at the east end of Upper Manitou Lake; a mile east of Fort Frances on the Rainy River; near Rat Portage; near the mouth of Dorè River; in the original Huronian area, north of Lake Huron, particularly the Thessalon area; on Lake Temiscaming.

It is assumed that the iron-formation material cannot be other than Lower Huronian, and that the conglomerates must represent a basal horizon of the Upper Huronian. The break between the Upper and Lower Huronian thus represented is a most profound one, and affords a good basis for the correlation of the Huronian formations. It is further suggested that this great unconformity may be the same as that between the Upper and Lower Huronian formations on the south shore of Lake Superior and in Minnesota.

Comment.—As stated by Dr. Coleman a number of the conglomerates above mentioned have been regarded by Pumpelly, Irving, Van Hise, and other United States geologists, as basal to the Lower Huronian — on structural evidence. Dr. Coleman places them in the Upper Huronian because they contain fragments of iron formation material which are assumed to be Lower Huronian. According to the generally accepted ideas of the number and relations of the pre-Cambrian

iron bearing formations, this assumption is perfectly justified and the conclusion follows as to the Upper Huronian age of the typical conglomerates mentioned.

But, lately evidence has been accumulated pointing to a conclusion of a rather radical nature. This evidence has been such that Van Hise[1] in a general article on the iron bearing formations of the Lake Superior country just published, describes *three* iron bearing formations, the Upper Huronian, Lower Huronian, and *Archean*. The most important of the Archean iron bearing formations are the Vermilion and the Michipicoten.

Van Hise himself in his published articles on the pre-Cambrian has persistently maintained the essentially non-clastic nature of the Archean, and the post-Archean age of all the iron bearing formations of the Lake Superior country. But new evidence on the subject, secured principally during the past year, has been so decisive that he has not hesitated to announce as proven the existence of an Archean or Basement Complex iron-bearing formation.

If there is an Archean iron formation, to which the Michipicoten and Vermilion iron formations belong, then Dr. Coleman's argument as to the Upper Huronian age of conglomerates containing iron formation fragments is rendered ineffective, and the conclusions indicated by the structural evidence that the great conglomerates and accompanying rocks above described are Lower Huronian must stand, until decisive evidence to the contrary is found.

Grant[2] describes and maps the Upper and Lower Keweenawan copper-bearing rocks of Douglas county, Wisconsin. The Lower Keweenawan appears in a broad belt running from northeast to southwest across the county, widening toward the southwest, and in a small belt cutting through the southeastern corner of the county. It consists mainly of basic lava flows, associated with which, in the area in the southeast corner of the county, are a few beds of conglomerate composed of débris of the closely adjacent underlying rocks. The Upper Keweenawan appears in a broad belt in the southeastern part of the county between the two belts of Lower Keweenawan rocks. It

[1] The iron-ore deposits of the Lake Superior region, by C. R. VAN HISE: Twenty-first Ann. Rept. U. S. Geol. Surv., Pt. III, 1901, p. 322.

[2] Preliminary Report on Copper Bearing Rocks in Douglas county, Wisconsin, by U. S. GRANT: Wisconsin Geological and Natural History Survey, Vol. VI, 1900, pp. 55.

is a series of conglomerates, sandstones and shales. In a belt north of the northern belt of Lower Keweenawan rocks, extending from these rocks to the shore of Lake Superior, is the Lake Superior sandstone (Cambrian). This is either flat-lying or dips slightly toward Lake Superior. The junction of the sandstone with the Lower Keweenawan is marked by a fault, along which the Lake Superior sandstone has been depressed, in some places probably as much as several hundred feet.

The Upper and Lower Keweenawan belts form a syncline, the axis of which runs northeast and southwest through the center of the tract underlain by Upper Keweenawan rocks.

While the Keweenawan rocks of this area are the same in kind and age as are the productive copper-bearing rocks of Keweenaw Point, the probable unproductive character of the Douglas county rocks is intimated.

Alexander Winchell[1] prefaces a detailed petrographical description of certain phases of the gabbroid rocks of Minnesota with a brief account of the general succession in structure of formations in northeastern Minnesota. This is essentially the same as given by N. H. Winchell[2] in Volumes IV and V of the Minnesota State Survey. The correlation of this succession with the succession determined by the United States Geological Survey is discussed.

Comment.— Mr. Winchell's ideas as to succession and structure determined by the United States Geological Survey are naturally derived mainly from Bulletin 86 of the Survey and from the "Principles of Pre-Cambrian Geology" published in the Sixteenth Annual Report of the Survey. However, since these reports have been issued, the United States Geological Survey has done somewhat detailed field work in northeastern Minnesota as a result of which the ideas of the United States geologists on the succession and correlation have been considerably changed. The new conclusions of the Survey are briefly outlined by Van Hise in the Twenty-first Annual Report. This paper should be referred to by anyone reading Mr. Winchell's discussion of the correlation.

[1] Mineralogical and Petrographic study of the gabbroid rocks of Minnesota, and more particularly of the plagioclastites, by ALEXANDER N. WINCHELL: American Geologist, Volume XXVI, 1900, General part, pp. 153–162, with geological sketch map of Northeastern Minnesota.

[2] See summaries, JOUR. GEOL., Vol. IX, pp. 79–86.

Van Hise and Bayley[1] describe and map the geology of a portion of the Menominee iron district of Michigan.

The pre-Cambrian succession is as follows:

Algonkian	Upper Menominee	Hanbury slate.
		Vulcan formation, subdivided into the Curry ore-bearing member, Brier slate, and Traders ore-bearing member.
	Unconformity	
	Lower Menominee	Negaunee formation.
		Randville dolomite.
		Sturgeon quartzite.
	Unconformity	
Archean	- - - - -	Granites and gneisses, cut by granite and diabase dikes.
		Quinnesec schists, cut by acid and basic dikes and veins.

In general the Algonkian rocks constitute a trough bounded on the north by the Archean rocks.

The Archean.— The Quinnesec schists are dark green or black basic schists and spheroidal greenstones, cut by large dikes of gabbro, diabase, and granite, and by smaller dikes of a schistose quartz porphyry. These occur in two areas, one along the Menominee River to the south of the Huronian rocks, and another in the west-central end of the district.

Bordering the Algonkian trough on the north is a complex of granites, gneisses, hornblende schists, and a few greenstone schists, all cut by dikes of diabase and granite. This complex is called the "Northern Complex." Most of the Archean rocks are igneous. Although there is no evidence of this, some of the fragmental tuffs may have been water-deposited. The Quinnesec schists and the Northern Complex are called Archean because they resemble lithologically other areas of Archean rocks in the Lake Superior country, and they both underlie the Algonkian series. The Northern Complex underlies the series with unconformity. The Quinnesec schists have

[1] The Menominee special folio, by CHARLES R. VAN HISE and S. W. BAYLEY: Geological Atlas of United States, Folio No. 62, U. S. Geol. Surv., 1900.

not been observed in contact, and hence the presence or absence of a normal erosion unconformity cannot be inferred.

The Lower Menominee series.— The formations of the Lower Menominee series are observed only in the center and on the northern side of the Menominee trough. The Sturgeon formation is composed mainly of a hard white vitreous quartzite forming a continuous border of bare hills bordering the Archean complex. At its base is a coarse conglomerate made up of débris from the underlying Archean complex. The belt is in general a southward dipping monocline with dips varying from 25° to perpendicularity, although there are many reverse dips to the north. Its thickness is placed at from 1000 to 1250 feet.

Above, the Sturgeon quartzite grades into the Randville formation which is mainly a homogeneous dolomite interstratified with siliceous or argillaceous layers. This formation appears in three belts. The northern one is just south of the belt of the Sturgeon quartzite. The central belt is on the north side of Lake Antoine for a portion of its length, passes eastward between the Cuff and the Indiana mines, and ends at the bluff known as Iron Hill in the east half of Sec. 32, T. 40 N., R. 29 W. The southern belt of dolomite extends all the way from the western side of the sandstone bluff west of Iron Mountain to the village of Waucedah, at the eastern end of the mapped area. Structurally the northern belt of dolomite is a southward dipping monocline, while the two southern belts are anticlines. The thickness is not determined on satisfactory evidence, but is probably 1000 feet or more. The Randville formation is found, in a number of mines. in contact with the basal formation of the Upper Menominee series Here there is a coarse conglomerate in the basal part of the overlying formation indicating unconformity.

The Negaunee formation, overlying the Randville dolomite, is represented in the district by so few and so small outcrops that it is mapped with the Vulcan formation. Its presence is inferred mainly from the occurrence of abundant iron formation débris in the basal conglomerate of the Upper Menominee formation, showing that the Lower Menominee iron-bearing series must have been present. In the Marquette district an iron-bearing formation (the Negaunee) occupies an exactly similar stratigraphical position.

The Upper Menominee series.—The formations between the unconformity at the top of the Lower Menominee and the unconformity at

the base of the Lake Superior sandstone, are placed in the Upper Menominee series. These occur in two great series, the Vulcan and the Hanbury.

The Vulcan formation is unconformable above the upper part of the Lower Huronian, which for most of the district is the Randville formation, and unconformable below the Hanbury slate. For parts of the district the Vulcan iron-bearing formation does not appear at all between the dolomite and the slate and its absence is explained by the unconformity between the Vulcan formation and the Hanbury slate. The Vulcan formation embraces three members. These are, from the base up, the Traders iron-bearing member, the Brier slate, and the Curry iron-bearing member. They are mapped as a single formation. The principal area of the Vulcan iron formation is in the belt 900 to 1300 feet wide, following the sinuosities of the southern border of the southern belt of Randville dolomite. It is generally absent north of the southern belt except at the east end where it appears at the Loretto mine and eastward. The second important area of Vulcan iron formation stretches off about five miles along the south side of the central dolomite belt running north of Lakes Antoine and Fumee, and ending somewhere about the east line of Range 30 West. At the east end of the dolomite area the iron-bearing formation appears in the lean slates at Iron Hill. The third stretch of country in which the iron-bearing beds are to be expected is that which borders the northern dolomite belt, but while pits have shown the existence of the formation here its distribution is unknown. The other areas in which the Vulcan formation may occur are those bordering the Quinnesec schists, but this has not yet been determined.

The Traders member consists of ferruginous conglomerate, ferruginous quartzite, heavily ferruginous quartzose slates and iron ore deposits. The Brier member consists of heavy black ferruginous and quartzose slates. The Curry member consists of interbedded japsilite, ferruginous quartzose slates and iron ore deposits. The relations of the Traders and Brier Hill members where there has been no disturbance of the strata is that of gradation. Where there has been disturbance, as in the vicinity of Norway, there has been a zone of differential movement between the two, resulting in slickensides and brecciated zones. Between the Brier slates and the Curry member there is gradation.

The Vulcan formation is bent into folds of several orders of

magnitude, the greater ones corresponding approximately to the folds in the underlying Randville dolomite. The total thickness of the formation is probably 600 to 700 feet.

The iron ore deposits of large size rest upon relatively impervious formations, which are in sucl. positions as to constitute pitching troughs. A pitching trough may be made (*a*) by the dolomite formation underlying the Traders member of the Vulcan formations, (*b*) by a slate constituting the lower part of the Traders member, and (*c*) by the Brier slate between the Traders and Curry members of the Vulcan formation. The dolomite formation is especially likely to furnish an impervious basement where its upper horizon has been transformed into a talc-schist, as a consequence of folding and shearing between the formations.

Unconformably above the Vulcan iron formation is the Hanbury formation, which forms three large belts in the syncline of the older rocks, and occupies a very large proportion of the district. The formation comprises clay slates, calcareous slates, graphite slates, graywackes, quartzite, ferruginous dolomite, and rare bodies of ferruginous chert and iron oxide. The formation is much thicker than any of the other formations of the district, but it is probably not thicker than 2000 or 3000 feet.

Wilder[1] describes and maps the Sioux quartzites and quartz porphyries of Lyon county, Iowa. No points concerning the stratigraphy or age have been added to those already given by other writers.

Bain[2] describes the geology of the Wichita Mountains. Gabbros and porphyries of pre-Cambrian and probably of Archean age are present. The gabbro is more prominent in the western portion of the mountains, being especially well developed in the Raggedy Mountains, and the porphyry is more common in the eastern part of the mountains, being typically developed at Carrollton Mountain.

Matthews[3] gives a detailed petrographical description of the granites of the Pike's Peak quadrangle of Colorado. They are referred to the late Algonkian period.

[1] Geology of Lyon county, by FRANK A. WILDER: Iowa Geol. Surv., Vol. X, 1899, pp. 96–108.

[2] Geology of Wichita Mountains, by H. FOSTER BAIN: Bull. Geol. Soc. Am., Vol. XI, 1900, pp. 127–144, Pls. XV–XVII.

[3] The Granite Rocks of the Pike's Peak Quadrangle, by A. B. MATTHEWS: JOUR. GEOL., Vol. VIII, 1900, pp. 214–240.

Cross[1] maps and describes the geology of the Telluride quadrangle, Colorado, and briefly sketches the geology of the San Juan region, of which the Telluride quadrangle is a part.

In the Telluride quadrangle, along Canyon Creek north of Stony Mountain, is a small body of upturned quartzites, with an intercalated rhyolite sheet, which have been referred to the Algonkian. The quartzites are coarse and grade into fine conglomerate.

Ancient granites, gneisses, and schists are known in the Animas Valley and in the Uncompahgre plateau. These rocks have usually been considered as belonging to the Archean, but some of them are probably younger than the great series of quartzites exhibited in the Needle Mountains to the south, and younger than the quartzites beneath the volcanics in the canyons of the Uncompahgre, above Ouray, which have been referred to the Algonkian. These quartzites stand on edge or have been greatly disturbed. The relations of these isolated exposures to contemporaneous formations elsewhere are unknown.

Spurr[2] maps and briefly describes the Archean[3] granite of the Aspen district of Colorado. This is unconformably below and in direct contact with sediments of upper Cambrian age.

Davis[4] in a general account of a trip through the Colorado Canyon district briefly describes certain features of the pre-Cambrian geology. He calls attention to the extraordinary evenness of the floor of schists with granite dikes (Archean) upon which the Chuar and Unkar terranes (Algonkian) rest. The floor for the Paleozoic strata is somewhat less regular than the floor for the Unkar. In two places the pre-Cambrian rocks rise higher than the basal Tonto (Cambrian) sandstone. The Archean schists beneath the Unkar have a steep and regular slope, indicating uniform resistance to erosion. Where, beneath the Tonto, they show a bench, it is taken to indicate a softer character at this point, probably due to a longer period of pre-Tonto weathering.

[1] Telluride Folio, Colorado, by WHITMAN CROSS: Geol. Atlas of the U. S., No. 57, 1899.

[2] Geology of the Aspen Mining District, Colorado, with Atlas, by J. E. SPURR: Mon. U. S. Geol. Surv., No. 31, 1898, pp. 1–4.

[3] The term Archean is evidently used in the sense of pre-Cambrian.

[4] Notes on the Colorado Canyon District, by W. M. DAVIS: Am. Jour. Sci., 4th ser., Vol. X, 1900, pp. 251–259.

Blake[1] refers to the Archean the thick layers of gneiss forming the southern flank of the Santa Catalina Mountains, Arizona. The gneiss is in flat layers representing beds. A part of it is augen gneiss; other layers are quartzose and seemingly quartzites.

Knight[2] in connection with the discussion of the artesian basins of Wyoming gives a brief description, accompanied by a map, of the geology of the state. Algonkian and Archean rocks are present. The Archean rocks consist mainly of granite, in places cut by dikes of porphyry containing mineral ores, which can be seen in typical exposure at Sherman, Laramie Peak, east of Whalen Canyon, along the Big Horn, Wind River, Gros Ventre, Medicine Bow, Ferris, Seminoe, and Owl Creek ranges, along the Sweetwater River, a few miles northwest of Rawlins, and north of Clark's Fork, in Big Horn county.

The Algonkian rocks are for the first time separated from the Archean. They consist of schists in great profusion, marbles, and quartzites, all cut with dikes of eruptive rocks. They occur in granite basins in unconformity with the Archean, and form important bands in numerous localities. The strike of the series varies from north to northeast and the dip of the strata is seldom less than 65–75°. The thickness of the entire series has not been absolutely measured, but including the eruptive band, which does not form an important part, the maximum thickness in Wyoming is about 20,000 feet. Typical areas have been found in the Black Hills in Wyoming, and occasional outcrops from that place to the Hartville hills — one exposure being east of Lusk, another at Rawhide Butte, and a large one in Whalen Canyon. They also occur at Halleck Canyon, Plumbago Canyon, in the Medicine Bow Mountains, nearly all of the Sierra Madre Mountains, in the Seminoe Mountains and in the Sweetwater mining district of the Wind River range. None of these localities have been examined in detail; but sufficient work has been done to prove that these rocks were at one time sedimentary, and that they have been changed by metamorphism to schists. In the Sweetwater districts the rocks are chiefly schists; but there are many bands of erruptive rock that form dikes which follow the strike of the formation.

[1] Mining in Arizona, by WM. P. BLAKE: published in report of the Governor of Arizona to the Secretary of the Interior, Washington, 1899, p. 142.

[2] A preliminary Report on the Artesian Basins of Wyoming, by WILBUR C. KNIGHT: Wyoming Experiment Station, Bulletin No. 45, 1900. Part on pre-Cambrian, pp. 111–116. With geological map. This is the first geological map of Wyoming that has appeared.

Weed[1] maps and describes the pre-Cambrian rocks in the Fort Benton and Little Belt Mountains quadrangles of Montana.

The Archean rocks are found only in the Little Belt range in the southwestern part of the Fort Benton quadrangle and in the northwestern part of the Little Belt Mountains quadrangle. They are gneisses and schists of various kinds, and of somewhat uncertain origin. They are, in part at least, of igneous origin, and none of them show any traces of sedimentary origin. Their relations to the Algonkian rocks are those of unconformity. The Algonkian rocks are found in the mountain tracts of the Little Belt range, in Castle Mountain, and in the low range crossed by Sixteenmile Creek in the southwest corner of the Little Belt Mountain quadrangle. They are divided into the Neihart quartzite and the Belt formation,[2] both of which are parts of what Mr. Walcott has called the Belt Terrane.

The Neihart quartzite is a hard pink and gray quartzite forming the base of the Belt Terrane for this area. It is found in the vicinity of Neihart in the Little Belt Mountains. Its thickness is about six hundred feet. The Belt formation consists mainly of slaty, siliceous shales, but also contains interbedded limestone and quartzite. Fossils found in this series (in the shales above the formation which Mr. Walcott has named the Newland limestone member of the Belt Terrane), represent the earliest forms of life yet known. Near Neihart the Algonkian period is represented by 4000 feet of beds, while further south and west the thickness is much greater.

Overlying the Algonkian rocks conformably are rocks containing Middle Cambrian fossils. North of Neihart they rest directly on the Archean.

Reconnaissance geological surveys in Alaska and adjacent portions of British Columbia, by United States and Canadian government parties, have shown the basal rock over considerable areas to be a granite, which is provisionally assigned to the Archean.[3] Such granite

[1] Fort Benton and Little Belt Mountains Folios, by WALTER HARVEY WEED: Geol. Atlas of the U. S., Nos. 55 and 56, 1899.

See also Geology of the Little Belt Mountains, Montana: Twentieth Ann. Rept. U. S. Geol Surv., 1898–9, Pt. III, 1900, pp. 278–284.

[2] The Belt formation includes the various lithological members of the Belt Terrane which Mr. Walcott has named the Chamberlin shale, the Newland limestone, the Greyson shale, the Spokane shale, and the Empire shale.

[3] Usually in the sense of pre-Cambrian.

is reported as occurring along the Pelly and Dease Rivers (Dawson[1] and Hayes;[2]) to the west, between the northern base of the St. Elias Mountains on the Yukon River (Hayes[3]); along the Upper Tanana River (Allen[4] and Brooks[5]), which is correlated by Spurr with the granite along the Pelly River; along Fortymile Creek, a tributary of the Yukon near the Canadian-Alaskan boundary (Spurr[6]); forming the core of the Kaiyuh Mountains (described by Dall,[7] referred to Archean by Spurr[8]); possibly forming the core of the Alaska Peninsula and the Aleutian Islands (noted by Dall[9] and Purington,[10] referred to Archean by Spurr[11]).

C. K. LEITH.

On Rival Theories of Cosmogony. By the REV. O. FISHER. *American Journal of Science,* June 1901, Pp. 414–422.

In this article the author has brought the current gaseo-molten hypothesis of the origin of the earth into comparison with the hypothesis of gradual accretion without a molten state recently advanced by Chamberlin, and has endeavored to test the tenability of the newer hypothesis by subjecting some of its fundamental postulates to mathematical and physical inquiries. The author disclaims holding a brief for either hypothesis and well sustains his claim to an impartial attitude.

[1] GEORGE M. DAWSON: Geological Natural History Survey of Canada, Vol. III, Pt. I, 1887–8, p. 34B.

[2] C. WILLARD HAYES: Geographic Magazine, Vol. IV, 1892, p. 139.

[3] Loc. cit., p. 139.

[4] LIEUTENANT H. D. ALLEN: Expedition to the Copper, Tanana, and Koyukuk Rivers, Senate Documents, Washington, 1897, p. 159.

[5] A. H. BROOKS: Twentieth Ann. Rept. U. S. Geol. Surv., Pt. VII, 1900, pp. 460–465.

[6] J. E. SPURR: Eighteenth Ann. Rept. U. S. Geol. Surv., Pt. III, 1898. pp. 134–140.

[7] W. H. DALL: Seventeenth Ann. Rept. U. S. Geol. Surv., Pt. I, 1896, pp. 862, 863.

[8] J. E. SPURR: Twentieth Ann. Rept. U. S. Geol. Surv. Pt. VII, 1900, pp. 235 and 241.

[9] W. H. DALL: Seventeenth Ann. Rept. U. S. Geol. Surv., Pt. I, 1896, p. 135.

[10] C. W. PURINGTON: Manuscript map referred to by Spurr.

[11] J. E. SPURR: Twentieth Ann. Rept. U. S. Geol. Surv. Pt. VII, 1900, pp. 233–235.

He cites at the outset a difficulty, "perhaps more apparent than real," encountered by the newer hypothesis in the sporadic arrangement of the meteoric material which, if like known meteorites, would differ from the existing surface rocks. This difficulty, however, loses much, if not all, of its force when the effects of volcanic action are considered. The hypothesis assumes that the interior heat which arises from compression gives rise to the melting of certain constituents of the rock mass, and that these, previous to eruption, undergo magmatic differentiation into the well-known igneous rocks and probably into others which are but rarely ejected because of their high specific gravity, as the iron-bearing basalt of Disco Island, Greenland, and other extremely basic rocks of the ferro-magnesian type. Volcanic action is assumed to have begun effectively before the growing earth reached the size of the moon and all accretions subsequently made would be more or less invaded and overflown by igneous intrusions and extrusions of differentiated lava. In the closing stages of the earth's growth, the infall of meteoric matter declined gradually to an inappreciable amount, while the volcanic action is thought to have continued with relative vigor for a notable period after the essential cessation of growth, and to have perpetuated itself in less activity down to the present time. If the moon may be taken as an illustration of the prevalence and effectiveness of surface vulcanism in a body one eightieth of the earth's mass, it does not seem violent to suppose that the original meteoric matter of the earth would be deeply buried under surface lava flows and tuffs in the closing stages of its growth. Recent studies in the Lake Superior region, in Scandinavia, and in Lapland seem to concur in showing that the oldest known rocks consist of such lava flows and pyroclastic layers associated with some small amounts of ordinary clastic material, all mashed into schistosity. Into these schists, the great granitic series were intruded. Under the newer hypothesis these intrusions are to be regarded as merely a continuation of the earlier active vulcanism which was then more largely basic, but which had now, in the progress of magmatic differentiation, attained a dominant acidic character, perhaps as the partial complement of the earlier basic flows of the schist series or of the later basic flows of the Algonkian. The "fundamental gneiss" does not, therefore, appear, in the light of these recent studies, to be *fundamental*, nor does the "basement complex" appear to be *basal*. These recent investigations seem to bring the Archean series into almost

ideal conformity with the accretion hypothesis, if under that hypothesis the process of accretion is conceived as dying away gradually by a transition into a stage of dominant vulcanism, which in turn gradually passes into the present phase of dominant aqueous activity. On the other hand, progressive investigation seems more than ever to give negative results in the line of the discovery of "the original crust" of the hypothetical molten stage, and the survival of the older hypothesis will perhaps require the recognition of a dominant eruptive stage similar to that postulated by the newer hypothesis, to which all or most of the Archean rocks are to be referred. In the light of these late Archean investigations, the difficulties of the old hypothesis seem at least as great as those of the new, for the old hypothesis must account for the non-appearance or scant appearance of "the original crust," while the new must account for the non-appearance or scant appearance of the supposed highly basic, magnesian, iron-bearing meteoric matter. The new hypothesis has the advantage of having theoretically postulated in advance what field studies are now bringing into recognition in spite of prepossessions inherited from the older view.

Passing the problem of superficial constitution as not necessarily serious, Fisher justly regards the increase of internal density and high internal temperature as incontestable facts of radical importance, and inquires how these facts may be accounted for on the meteoric theory. He assumes the average density of the meteoric matter to be nearly that of average surface rock, 2.75, and adds that "if this is too low, the arguments based upon it will not be affected in any great degree." Fisher feels tolerably certain that the law of internal density is fairly represented by Laplace's law, which is that "the increase of the square of the density varies as the increase of the pressure." In the case of a slow growth by solid accretion, the internal density must be mainly referred to compression. If, however, the specific gravity of the original meteoric material be taken at some figure between 3.5 and 4, as derived from known meteorites (Farrington's figure in 3.69), the amount of compression is appreciably less than on the assumption of 2.75 made in the computations. Fisher finds that at a depth of 400 miles, where by Laplace's law the density should be 3.88 the compressibility would be 1.4021×10^{-6}. "This may be looked upon as a small compressibility, seeing that the compressibility of water similarly measured is 4.78×10^{-5} or nearly forty times as great." The linear

dimensions would be reduced about one tenth. "At the center the compressibility similarly measured would be very small, viz., 2.5×10^{-7}, while the condensation would be large, viz., 0.744."

In the absence of direct measurements on the compressibility of rocks, the author computes its value from the values of Young's modulus and the modulus of rigidity which have been obtained in some instances, and compares the result with the theoretical compressibility of surface rocks deduced from Laplace's law. Respecting the results, he remarks that "it is certainly not a little remarkable how closely this value ranges with those found by experiment. It is of the same order of magnitude but rather smaller than the average." He adds:

> We find here a somewhat strong presumption in favor of the view that the earth consists throughout of matter not very dissimilar from what we know at the surface, and that the internal densities are due rather to condensation than to the presence of heavier substances such as metals. But it is not a proof of this.

Respecting the alternative view that the greater density toward the center is due to heavy metals, Fisher says:

> We may probably dismiss the supposition that these all fell in first, and only regard them as segregated from a uniform mass of some kind, and having gravitated towards the center. This implies a condition of liquidity. If the materials were solid this separation could not have occurred. Now the only force that we know of that could cause the denser materials to move by a kind of convection towards the center is gravity; and in a solid gravity would not have that effect. Moreover, it must not be forgotten that gravity continually diminishes as we go deeper into the earth, and that at the center bodies have actually no weight. It is greatest at the surface, and if not competent to segregate downwards the heavy particles of a rock at the surface, which we know it is not, still less could it have that effect near the earth's center.
>
> Neither can we attribute this segregation to pressure; for pressures act equally upon the surface of heavy or light materials. If we had a layer of mixed shot and sand, no steady pressure laid upon it would force the shot to the bottom and bring the sand to the top.
>
> It seems, therefore, that the view that the denser materials in the interior consist of heavy metals necessitates a condition of liquidity of the whole, which accords more readily with the nebular than with the meteoric theory of its origin. For we may imagine that in a nebular mass cooling from the exterior, the first change from a nebulous or gaseous state would be the formation of a rain of condensed particles falling downwards, which would continue until the whole mass became liquid, and thus the heavier elements would begin to

collect towards the center. In this case the highest possible interior temperature would be that at which the gaseous first assumed the liquid condition under the pressure at the depth.

Paradoxical as it appears, it is therefore possible that the temperature in the interior may have been rendered higher by a conglomeration of cold solid meteorites than by the cooling of a nebula.

We have no means of judging whether the meteorites would come in rapidly or slowly, but in either case if we take no account of the heat arising from impact, the amount produced by condensation would be the same; the only difference in the two cases being that it would be generated in a less or greater time. In the meanwhile a covering of a badly conducting material would concurrently accumulate, preventing the rapid escape of this heat, and at the same time increasing the pressure, the compression, and the heat.

To form an idea of the temperature which would be produced by the condensation of matter of surface density to the density now existing at any given depth within the earth, not taking into account its diffusion by conduction or otherwise, we require to know the work which has been expended upon it. Now we can estimate this in the following manner. Conceive the earth to have been built up of meteorites falling in, so that shell after shell accumulated until the globe attained its present size. Then, fixing the attention upon a particular unit volume, say a cubic foot, of the substance, and omitting atmospheric pressure, it would successively be subject to every degree of pressure from zero, when the shell of which it formed a part was not covered up, until the present pressure was reached, when it was buried to the depth at which it now lies. If then we know the relation between the pressure and the compression at every depth at the present moment, it will give us the relation between the pressure and the compression which that particular volume has obeyed during the course of ages; that is to say, we can judge how much compression any given pressure would have produced in the substance under the conditions involved.

Laplace's law of density being based upon the assumption that the increase of pressure within the earth is proportional to the increase of the square of the density, in terms of a pressure of one pound upon the square foot, this leads to the result, that the pressure at the depth where the density is ρ is equal to $5.9\times10^7\ (\rho^2-s^2)$ [where s=density of surface rock and ρ= density of rock at the depth under consideration].

If we accept Laplace's law, this expresses a fact, whether the increase of density is due to condensation by pressure or to increased density in the intrinsic nature of the matter. But if we assume that the increase of density is caused solely by the pressure, then the above relation gives the amount of pressure which would reduce matter of density s to matter of density ρ under circumstances existing within the earth. It will therefore remain true if the

matter changes its state from solid to liquid, and from liquid to gas. If, for instance, we wished to apply a pressure which would reduce surface rock to the density 3, it ought to be $5.9\times10^7\ (9-2.75^2) = 8.481\times10^7$ pounds per square foot, supposing no heat be allowed to escape. If the experiment could be made, it would afford a test of the truth or otherwise of the present hypothesis.

When we know the relation between the pressure and the condensation which it would produce, it is feasible to estimate the heat which would be generated, and also the temperature, provided we assume the specific heat of the substance, which for surface rock has been determined. For instance, at the depth of 0.1 of the radius, or about 400 miles deep, where the density would be 3.88, the temperature produced by condensation would be 1.2608×10^8 Fahr., or 7.0044×10^4 Cent. [70,044°], while at the center the figures would reach 2.7756×10^8 Fahr., or 1.0242×10^8 Cent. [1,024,200°]. It seems at any rate that the meteoric theory would not fall short of accounting for temperatures as high as might be desired. It must at the same time be remembered that much of this heat would not be called into existence until the substance into which it was, as it were, being squeezed, had already been deeply buried under a badly conducting covering, so that the escape of heat would not take place as fast as it was generated, as would probably be the case with heat generated at the suface by impacts. Thus the hypothesis that the present high internal temperatures are due to compression seems quite admissible.

We may compare the above named temperatures with some that are known. Acheson, for instance, obtains 6500° Fahr. in his Carborundum electric furnace, and 3300° Fahr. has been obtained by the oxyhydrogen flame. These temperatures are contemptible compared with those mentioned above. The Hon. Clarence King, prolonging Dr. Barus' line for the melting point of diabase (which is 1170° C. at the earth's surface) to the earth's center, gives the temperature 76000° Cent., which is of the same order of magnitude as condensation would produce at only 400 miles depth.

Fisher considers the bearing of the temperature of lava as determined by Bartoli at Etna (1060°C. or 1932° F.) on the question, and finds that the theoretical depth at which this lava temperature would be produced by condensation would be about forty-three miles. The same temperature would be reached at the accepted gradient of 1° F. for sixty feet in about twenty-two miles.

It seems then that the hypothesis, that the internal densities are due to the condensation of matter of surface density, will not account for a temperature gradient originally as high as at present. [The computed gradient corresponds pretty nearly with the low gradient found at the Calumet and Hecla

mine.] Nevertheless the above observations upon the temperature of lava, and the comparatively small depth, forty miles, at which condensation of rock would be capable of producing it, together with the small amount of condensation necessary, viz., 0.041, render it quite probable that fusion may have ensued in the deep interior without the necessity of a greater amount of condensation than such materials might be supposed capable of under the enormous pressure to which they would be subjected, even allowing for the increase of the melting point under pressure. . . . . It will be noticed that a compression less than would be requisite of itself to produce the necessary density would be sufficient to produce the requisite temperature for fusion. But while any stratum was cooling by the conduction upwards of its own heat of compression, it would be receiving heat from regions below, where, so long as condensation was going on, the materials would grow hotter and hotter. It seems therefore possible that the upper layers, forming what we call the crust of the earth, may have received sufficient heat supplied from below to render the temperature gradient at the present time higher than it was originally, and that even those Archean rocks, which are by many thought to have been once melted, do not necessarily prove that the earth was not built of cold meteorites.

The presence of water upon the earth has to be accounted for, and the meteoric theory does not easily lend itself for this purpose. Not only is water present in the ocean and in the atmosphere, but also in a state of solution in the interior, as is testified by the enormous amount of steam emitted by volcanoes, and by cooling lava. It does not seem possible that molten rock can imbibe water from without, because it would be driven away instead of attracted, since the superficial tension of a substance diminishes as the temperature rises.

The problem of accounting for the vast quantities of steam emitted by lavas is shared by both theories. Under the hypothesis of a molten earth, steam must have been absorbed either in the original molten state or during the later stages of segregation and ascent, neither of which alternatives seems to be free from difficulties. Under the meteoric hypothesis, it is assumed that hydrogen, carbon dioxide, carbon monoxide, and nitrogen were carried into the whole body of the earth by the infalling matter in some such degree as they are brought to the surface now by meteorites, and that these gases, joined with oxygen derived from the partial reduction of the oxides of the meteoric matter when subjected to the high temperatures of the interior, were extruded by volcanic and similar means and gave rise to the ocean and atmosphere. Under this hypothesis the volcanic gases are regarded as mainly original and as merely lingering expressions

of the process that was much more intense during the later stages of the earth's growth. Cosmic accretions, which may be a notable factor, would be equally functions of either hypothesis so far as the maintenance of the atmosphere and ocean is concerned.

In submitting the newer hypothesis to the test of physical principles and mathematical computations, Fisher has done it an honor that is sincerely appreciated. By showing that its more radical features lie within the tenable limits of theory, he has helped to give it a place as a genuine working hypothesis; and as such it may have some stimulating value as a competitor of the gaseous and molten theory which has practically monopolized geological opinion for the past century.

T. C. C.

Glacial Sculpture of the Bighorn Mountains, Wyoming. By FRANÇOIS E. MATTHES. Extract from the Twenty-first Annual Report of the United States Geological Survey, 1899–1900. Washington, 1900.

Glaciation affected the crest of the Bighorn Mountains for more than thirty miles. The range was not covered by a continuous ice cap, and glaciation was confined to valleys. The mountains abound in well developed, elongate, valley-like cirques, which have been but little altered by postglacial changes. The author indorses Johnson's view of the origin of cirques, namely, that they are due to sharply localized and abnormally vigorous weathering, by rapid alternation of freezing and thawing at the exposed bottoms of *bergschrunds*. Mr. Matthes' studies have led him to the conclusion that the location of the *bergschrunds* in any valley is determined by the depth of the névé.

The longest glacier of the Bighorn Mountains is said to have been eighteen miles in length, its terminus reaching down to an altitude of less than 7000 feet. The thickness of the larger glaciers was 1000 to 1500 feet. Small glaciers still exist in the highest part of the range, a little below 44° 30′, at an altitude of about 12,000 feet.

In addition to the account of the effects of the active valley glaciers on topography, the author discusses the effect of inactive snow and névé. The névé effects are described under the term "nivation," and the "nivated" valleys are distinguished from the glaciated valleys. This, so far as we are aware, is the first attempt to analyze the effects of inactive ice and névé on topography. The discussion even involves

the effects of snow banks. The thickness of the névé fields which did not become glaciers is estimated to have been 100 to 150 feet, and the conclusion is reached that, on a grade of about 12 per cent., the névé must attain the thickness of at least 125 feet in order to have motion.

Certain phases of the problem of glacial motion are touched, and the conclusion reached that the cause of glacial motion is to be sought in the weight of the ice mass, and that it is independent of the temperature of the air. No attempt is made, however, to decide the real nature of glacial motion, or what processes are involved in it.

R. D. S.

Annual Report of the Board of Regents of the Smithsonian Institution, showing the Operations, Expenditures, and Condition of the Institution for the year ending June 30, 1899.

In the appendix accompanying the official report of the governing bodies and the secretary of the Smithsonian Institution, a complementary number of geological articles are introduced. These are, for the most part, republications, and include "On Lord Kelvin's Address on the Age of the Earth as an Abode Fitted for Life," by T. C. Chamberlin; "An Estimate of the Geological Age of the Earth," by J. Joly; "The Petrified Forests of Arizona," by Lester F. Ward; "Present Conditions of the Floor of the Ocean; Evolution of the Continental and Oceanic Areas," by Sir John Murray; "The Truth About the Mammoth," by Frederic A. Lucas; "Mammoth Ivory," by R. Lydekker; and "Review of the Evidence Relating to Auriferous Gravel Man in California," by William H. Holmes. Several of the physical and biological articles, and those relating to general aspects of science, also possess points of interest to geologists. C.

Recent Publications

—Becker, George F. Conditions Requisite to our Success in the Philippine Islands. An address delivered before the American Geographical Society, February 20, 1901. [Reprinted from Bull. of the Am. Geog. Soc., April 1901.]

Report on the Geology of the Philippine Islands. Followed by a version of Ueber Tertiäre Fossilien von den Philippinen (1895) by K Martin. [Extract from the Twenty-first Annual Report of the U. S. Geological Survey, 1899–1900. Part III—General Geology, Ore and Phosphate Deposits, Philippines.] Washington, 1901.

—Collie, George Lucius. Wisconsin Shore of Lake Superior. [Bull. of the Geol. Soc. of Am., Vol. XII, pp. 197–216.] Rochester, April 1901.

—Davis, W. M. An Excursion in Bosnia, Hercegovina, and Dalmatia. [From Bulletin, Vol. III, No. 2, Geog. Soc. of Philadelphia.]

An Excursion to the Grand Canyon of the Colorado. [Bulletin of the Museum of Comparative Zoölogy at Harvard College, Vol. XXXVIII. Geological Series, Vol. V, No. 4; with two plates.] Cambridge, Mass., May 1901.

The Geographical Cycle. [Paper read at the Seventh International Geographical Congress of Berlin in 1899.] Berlin, 1900.

—Dorsey, George A. Archæological Investigations on the Island of La Plata, Ecuador. [Field Columbian Museum, Publication 56; Anthropological Series, Vol. II, No. 5.] Chicago, April 1901.

—Dorsey, George A and H. R. Voth. The Oraibi Soyal Ceremony; The Stanley McCormick Hopi Expedition. [Field Columbian Museum, Publication 55; Anthropological Series, Vol. III, No. 1.] Chicago, March 1901.

—Dumble, E. T. I, Cretaceous of Obispo Canyon, Sonora, Mexico. [Reprinted from the Transactions of the Texas Academy of Sciences, Vol. IV, Part I, 1900.] II, Occurrence of Oyster Shells in Volcanic Deposits in Sonora, Mexico.

Geology of the Beaumont Oil Field.

Natural Coke of the Santa Clara Coal-Field, Sonora, Mexico. [Transactions of the American Institute of Mining Engineers, California Meeting, September 1899.]

The Iron Ores of East Texas.

The Oil Deposits of Texas.

—ELLIOT, D. G. A List of the Land and Sea Mammals of North America North of Mexico. [Field Columbian Museum, Publication 57; Zoölogical Series, Vol. II, No. 2.] Chicago, June 1901.

A List of Mammals obtained by Thaddeus Surber, in North and South Carolina, Georgia, and Florida. [Field Columbian Museum, Publication 58; Zoölogical Series, Vol. III, No. 4.] Chicago, June 1901.

The Caribou of the Kenai Peninsula, Alaska. [Field Columbian Museum, Publication 59; Zoölogical Series, Vol. III, No. 5.] Chicago, July 1901.

—FISHER, REV. O. On Rival Theories of Cosmogony. [From the American Journal of Science, Vol. XI, June 1901.]

—India, Geological Survey of. General Report for the Year ending March 31, 1901. C. L. Griesbach, Director. Calcutta, 1901.

—New Jersey, Geological Survey of. Annual Report of the State Geologist for the Year 1900. Trenton, N. J., 1901.

—NUTTING, C. C. The Hydroids of the Woods Hole Region. [Extracted from U. S. Fish Commission Bulletin for 1899, pp. 325–386. Date of publication, June 8, 1901.] Washington, 1901.

—OLDHAM, R. D. Beach Formation in the Thirlmere Reservoir. [Abstract of a paper read before the British Association, Bradford, 1900.]

—Øyen, P. A. Variations of Norwegian Glaciers. [Separataftryk af "Nyt f. Naturvidenskab," B. 39, H. 1. Kr. ania, 1901.] Christiania, April 1901.

—RABOT, CHARLES. Les Variations des Longueur Des Glaciers dans les Régions Artiques et Boréales. [Extrait des Archives des sciences physiques et naturelles Années 1899 et 1900.] Genéve et Bale, 1900.

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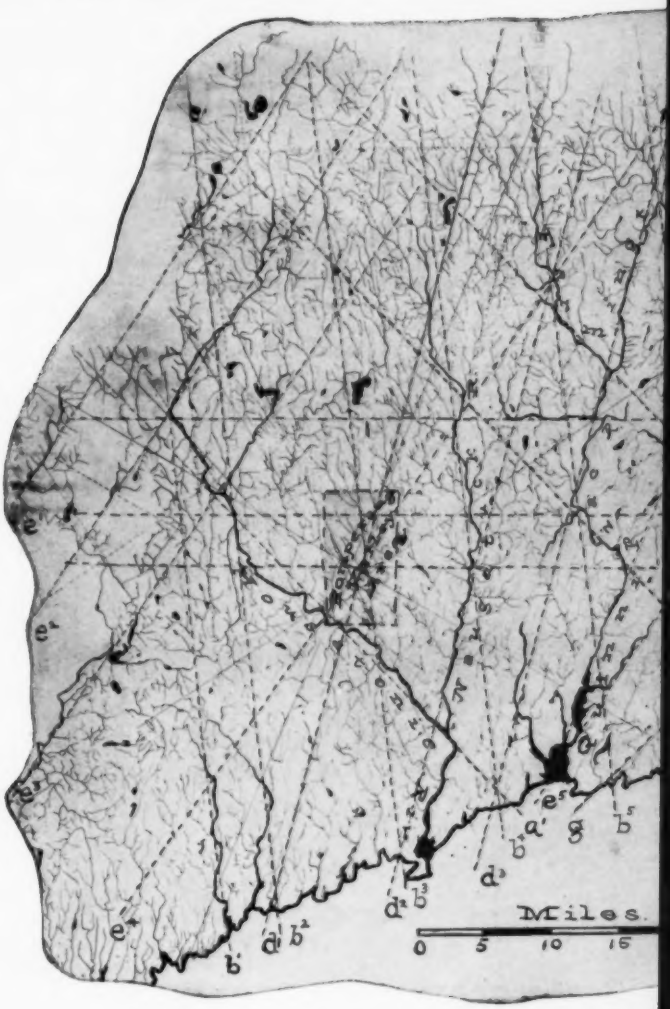
—SHIMEK, B. The Loess of Iowa City and Vicinity. Iowa Pteridophyta (Con.). Addenda to the Flora of Lyon County. [Excerpt from the Bulletin of the Laboratories of Natural History, State University of Iowa, Vol. V, No. 2, pp. 195-216.] May 1901.



RIVER MAP O

(Reduced from the two-sheet map of C

The dotted lines indicate the prominent "trough lines," which trend

a^1, a^2, etc., N. 44° W.
b^1, b^2, etc., N. 5° W.
c^1, c^2, etc., N. 5° E.
d^1, d^2, etc., N. 15° E.

Plate I

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llows:

c^1, c^2, etc., N. 33° E.	g, N. 48° E.
f, N. 20° E.	h^1, h^2, etc., N. 90° E.W.